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BY

EDWARD L. NICHOLS,
ERNEST MERRITT, and FREDERICK BEDELL

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JUNE, 1911

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THE

PHYSICAL REVIEW.

ON THE FREE VIBRATIONS OF A LECHER SYSTEM, USING A LECHER OSCILLATOR. I.[1]

By F. C. Blake and Charles Sheard.

IT was Professor Rubens[2] who first quantitatively demonstrated the existence of the free vibrations of a Lecher[3] system. Since then a great deal of work has been done on the subject of stationary waves in parallel wires, so much so in fact that it would seem that at best one could only repeat the work of others if he undertook a research along this line. Moreover, many theoretical papers[4] have appeared on the subject and one has only to attempt to correlate the experimental and theoretical parts of the subject as exemplified in the literature to convince himself that there is something still to be desired in this field. But it was the work of Blake and Ruppersberg[5] that led us to repeat Rubens's experiments under the better working conditions now attainable. Their work had shown us that experimentally at least there ought to be found solutions of such vexing questions as these—(*a*) ought the bridge to be taken into account and to what extent?[6] (*b*) are the currents in the Lecher system transverse, or longitudinal, or partly one and partly the

[1] Read before the American Physical Society at Chicago, November 26, 1910.

[2] Wied. Ann., 42, p. 154, 1891.

[3] Wied. Ann., 41, p. 850, 1890.

[4] Mention need be made of only three, viz., Cohn and Heerwagen, Wied. Ann., 43, p. 343, 1891; P. Drude, Wied. Ann., 61, p. 631, 1897; M. Abraham, "Theorie der Elektrizitat" (2d edition), Bd. 1, p. 347.

[5] Blake and Ruppersberg, Phys. Rev., Vol. XXXII., p. 445, 1911.

[6] See for instance Rubens, *l. c.*, p. 161.

other?[1] Intimately related with each of these are two other more general questions, (*c*) are the various frequencies in a freely vibrating Lecher system related to each other? and (*d*) if so, what are the relative intensities of these harmonics? It was hoped that further experimentation on this old problem would help to answer these questions. To what extent this hope was justified will show further along in these papers. A discussion of the work of previous investigators is accordingly reserved until after our own experimental results are presented.

APPARATUS.

The oscillator was of the Lecher type connected through two air-gaps and two water-resistances to the induction coil after the manner of Blake and Ruppersberg.[2] The coil used was a 10-inch coil attached directly to a 110-volt, 60-cycle A.C. lighting circuit, the condenser and interrupter being removed. As several different types of oscillators and primary circuits were used it seems best to describe them separately as the various phases of the work are touched upon. The bolometer used was the same as that employed by Blake and Ruppersberg. However, these writers did not make use of a check receiver and while their results cannot be materially in error on that account, nevertheless it was evident to us as we witnessed their work that the introduction of a check receiver would be a great improvement if one were to try for the greatest accuracy. Such a receiver was accordingly employed and of course two galvanometers were used. The one was a duBois-Rubens iron-clad, the other a Broca instrument. Their sensitiveness was 4.07×10^{-9} and 6.45×10^{-8} respectively for a period of 4 seconds. After being once set up it was not necessary to adjust them throughout the work.

EFFECT OF VARYING THE DISTANCE BETWEEN THE LECHER WIRES.

Employing a check receiver, we tried at first to get the free oscillations of the parallel system. Blake and Ruppersberg had found that the overtones of the free (?) system were not harmonic and after our results became known to them it appeared that the

[1] See Lecher, *l. c.*, p. 854; also J. J. Thomson, "Recent Researches," p. 466.

[2] Blake and Ruppersberg, *l. c.*

reason for this was because of the closeness of the coupling employed by them. Accordingly, we started with what we deemed a fairly loose coupling and hoped thereby to get the ideal free vibra-

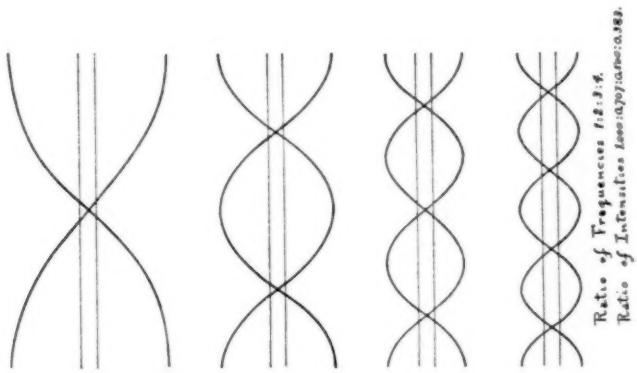

Fig. 1.

tions shown in Fig. 1. For this the oscillator consisted of two brass balls each 3/8 in. in diameter, bored out and filled in with steel

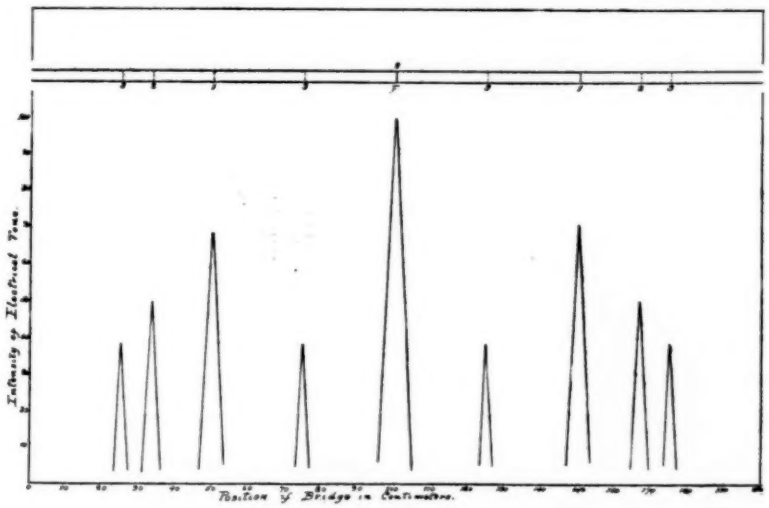

Fig. 1a.

cylinders tapered off to a truncated cone[1] at the spark-gap in oil. Soldered to these cylinders were copper wires attached to primary tin plates 5 cm. square. This made the total length of the oscillator

[1] This was the oscillator used by Blake, PHYS. REV., Vol. XXX., p. 678, 1910.

circuit up to the plates 28 cm. Opposite these plates, at a distance of 2 cm., stood the two secondary plates each 3 cm. square. The whole arrangement of the oscillator and Lecher circuits is shown in Fig. 2. The air-gaps were each 7 mm. long. The check receiver

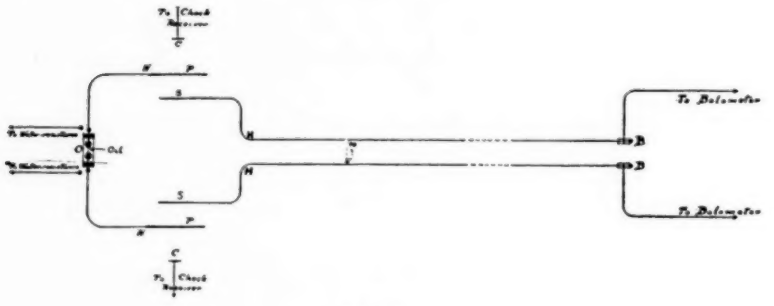

Fig. 2.

was a thermal couple of iron and constantan (diameter of wire 0.0208 mm.). It proved to be quite a problem properly to locate the check receiver with respect to the rest of the apparatus so as to accomplish the sole purpose of correcting the oscillator deterioration. Trial revealed the fact that it was readily influenced by stray radiation when only a short distance from the oscillator, so it was symmetrically placed about 50 cm. from the oscillator and two long equal lead wires led from it to small capacity plates each 1 cm. square placed 3 cm. away from the primary plates of the oscillator though parallel to them, as shown in the figure. The total length of the check receiver circuit was thus 3 meters. With this arrangement a Lecher curve was taken by moving a single bridge along the parallel wires. Plotting the check receiver readings against the bridge position showed a curve of sinusoidal nature and it became at once apparent that the check receiver was influenced by what might be called the mutual interaction of the oscillator and Lecher circuits, or better the back-action of the Lecher circuit upon the oscillator. This *back-action* will be spoken of again. A test experiment showed that this mutual interaction was present even though the check receiver was metallically protected from any stray radiation effects. The back-action upon the check receiver plates, *CC*, of Fig. 2 must have come from the secondary plates *SS through*

the primary plates *PP*. As we could not use the check receiver readings the curve was plotted with the oscillator deterioration uncorrected for and is shown in Fig. 3.

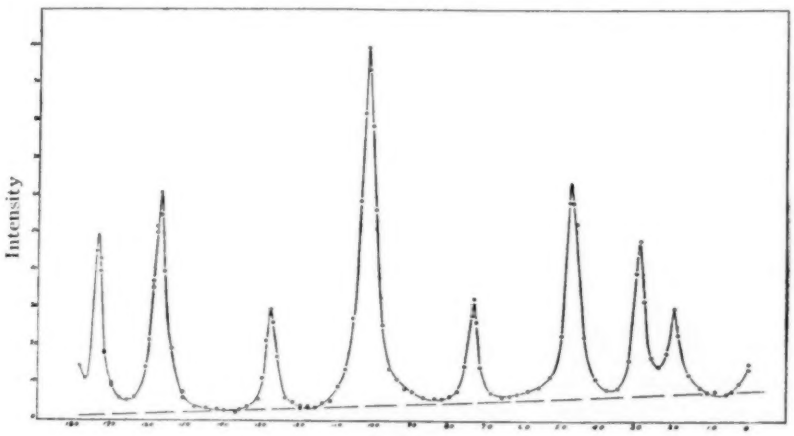

Fig. 3.

When it is remembered from Fig. 2 that the detecting system is at the free ends of the Lecher wires it is plain that the free vibrations shown in Fig. 1 will appear as Fig. 1*a* when properly interpreted. After comparing Fig. 3 with Fig. 1*a* no one will question the statement that we have in Fig. 3 a first approximation to the ideal case depicted in Figs. 1 and 1*a*. The following calculation shows, however, that Fig. 3 will not in all parts bear close theoretical scrutiny. The zero end of the 2-meter stick was placed vertically below the last bridge position obtainable on the Lecher wires at the bolometer end. Beyond this the wooden supports for the bridge and for the means of keeping the wires under tension occupied a linear space of 1.8 cm. The Leyden jars were themselves 1 cm. long and the small disc with its protruding knob of solder added 2 mm. The actual end of the wire was thus at -3 cm. Just as Blake and Ruppersberg found a decidedly better agreement between theory and experiment by considering that the wave is reflected only after it reaches *the end of the wire*, so do we find this true also. That this interpretation is justified will appear from the work using cylindrical capacities reported later in this work. Table I. shows that the mean fundamental wave-length λ_0 is 434

cm., of which one fourth is 108.5 cm. From the end of the wire to the bridge reading for the fundamental tone is 105.0 cm. giving as the equivalent value of the end-capacity 3.5 cm. of wire. The rest

TABLE I.

Distribution of Energy. [*Plate Capacities.*] *Potential Difference* $= \Phi_1 - \Phi_2 = 2\frac{|A|}{K}\cos\left(\frac{vx}{w} - \gamma\right) \cdot \cos(vt) \propto \sin\left[\frac{\pi}{2}\left(\frac{1}{n+1}\right) - 2\gamma\right]$. *Phase Change* $= 2\gamma$ $\left(\text{where } \tan\gamma = \frac{v}{w} \cdot \frac{K_0}{K} = \frac{2\pi K_0}{\lambda K}\right)$. ($n$ = no. of overtone.)

K_0/K (cms.).	l cms.	λ cms.	2γ	Tone.	Intensity.		
					Theory (Per Cent.).	Experimental (Per Cent.).	Difference.
3.5	105	434	5° 47′ 54″	Fund.....	100	100	—
				1st har.	62.7	62.7	0.00
				2d har.....	41.0	49.0	+8.00
				3d har.....	29.0	31.7	+2.70

of the calculation is collected into the table and it is seen that the agreement between theory and experiment is very satisfactory except for the second harmonic where the difference is almost 8 per cent. It will be shown later that undoubtedly an oscillator vibration swings in here *along with* the free second harmonic, thereby increasing its intensity.

Other curves were taken for distances between the wires as follows: 1 cm., 3 cm., 5 cm., 11.5 cm. Two of these are shown in Fig. 4. Curve *I* is for 3 cm., Curve *II* for 11.5 cm. For each of these curves the oscillator deterioration was corrected for by employing the check receiver readings in the following manner. Plotting the check receiver readings against the bridge position the curves of Fig. 5 were obtained. For 11.5 cm. distance between the parallel wires the sinusoidal nature of the curve was clearly shown, the oscillator evidently being in first class condition. Although the oscillator for the 3 cm. curve was not in such good condition, the curve shown cannot be much in error. The beginning of the 1 cm. curve is also shown, the oscillator being in unusually good condition, though the last half of the curve (not plotted) shows that the oscillator "went badly to pieces." The figures on

the right of the 3 cm. curve for the bridge position 10 cm. represent check readings at that position taken immediately after the bridge position indicated by the number written opposite the points. For

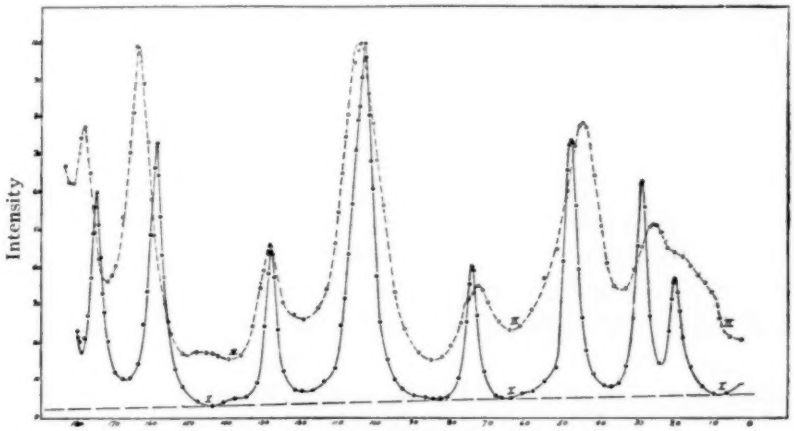

Fig. 4.

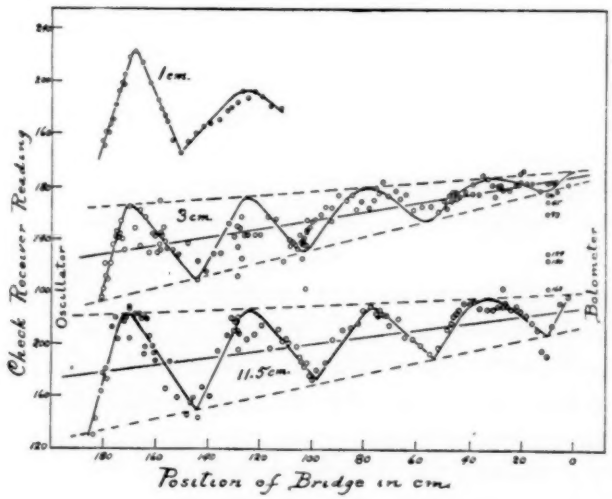

Fig. 5.

all the curves shown in Fig. 5 the bridge was moved toward the oscillator and the downward slope of the axes of the curves, as well as the 10-cm. check readings of the 3-cm. curve, shows the need of correcting for the oscillator deterioration. Since the check receiver

readings are themselves influenced by the bridge position a little thought will convince the reader that the oscillator deterioration is properly corrected for by multiplying the bolometer reading for a given bridge position by the ordinate for the sine curve of Fig. 5 and dividing by the ordinate for the axis of such curve. To show the order of magnitude of this correction it should be stated that it served to even up the intensities of any particular harmonic at the two ends of the Lecher system but in no case did it displace a maximum more than 3 mm.

It is seen from the curves of Fig. 4 that for increasing distance between the Lecher wires the fundamental maximum broadens out and the minima are less prominent. If one plots the ratio of the fundamental maximum to its own minimum (at 85 cm. say) for the different distances between the wires the curve shown in Fig. 6 is obtained. This curve shows a maximum at 3.4 cm. It would appear that, starting with this distance, as one decreases the distance between the wires the magnetic fields surrounding the two parallel wires nullify each other more and more and hence decrease the ratio of maximum to minimum. For zero distance between the wires one should expect this ratio to become unity and we have so extrapolated it in the curve. On the other hand, if we increase the distance between the Lecher wires it is plain that there must be an upper limit beyond which any further increase will begin to lessen the above ratio. For, theoretically, the free vibrations are essentially *longitudinal* vibrations such that the bridge serves only the purpose of enabling us to detect the vibrations without distorting them as to intensity or position. It is to be noticed that in Curve *II* of Fig. 4 (for 11.5 cm.) the system of vibrations is not the regular symmetrical system that it is for the lesser distances. It will be shown later (as indeed the curve for 5 cm. distance with the arrange-

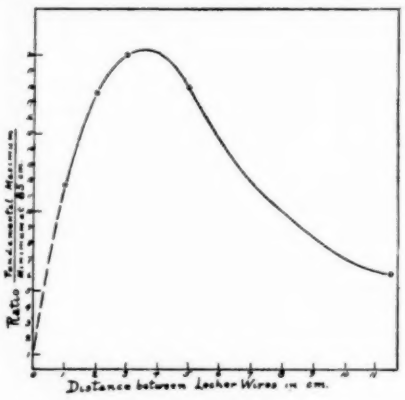

Fig. 6.

ment of Fig. 2 shows when plotted) that up to a distance of 5 cm. at least with a Lecher wire length of 175 cm. or more the presence of the bridge introduces no disturbing factor. That is, so long as the bridge length is not more than 3 per cent. of the Lecher length we may safely conclude that, although there is *necessarily always* current in the bridge wire whatever its position the two ends of the bridge wire may be said to have the same phase and hence the phase relations at the bolometer end of the Lecher system are the simple ones the theory demands. For a distance as great as 11.5 cm. this is not the case, as Curve *II*, Fig. 4, plainly shows. An inspection of this curve reveals an oscillator vibration at 9, 76.5 and 144 cm., giving 67.5 cm. for $\lambda/2$. Now it seems to us that the distance between two adjacent maxima of Fig. 5, viz., 45 cm., is the half wave-length of *some* vibration of the oscillator. These two oscillator vibrations of 45 cm. and 67.5 cm. half wave-length bear the ratio 1.50. In the light of the work of Blake and Ruppersberg and of evidence still to be spoken of we think these represent the two fundamental vibrations of the oscillator, due to the comparatively close coupling. This makes the true oscillator wave-length 115.8 cm. Now the distance *NON* (Fig. 2) was 28 cm. When one allows for the plates *PP* and for the balls at the spark-gap it is plain that the oscillator half wave-length could easily be 57.4 cm.

An attempt was made from the curves of Figs. 3 and 4 to test out the law that the potential difference between the Lecher wires is proportional to the logarithm of the ratio of the distance between the wires to their radius, but not enough attention had been paid to the equality of the other conditions to make this possible. To insure success in this effort one must have absolute control over the oil-gap and this we did not have at the time these curves were taken.

Modified Lecher System.

In the course of the work referred to above it became plain to us that two features of the experimental arrangement needed improvement. First, it was plain that the check receiver must be located so as to be free from the back-action of the Lecher system. And secondly, it became very desirable to have the degree of coupling readily alterable. Both of these conditions called for a modi-

fication of the apparatus. As to the first, it was clear that if one were able to free the check receiver from the back-action it would certainly be accomplished if at all by placing the check receiver as a high resistance shunt directly across the spark-gap in oil. Accordingly this was done and it proved at once the solution of the difficulty. Small platinum plates 1 cm. in diameter were arranged as electrodes of a high resistance, one on each side of the thermal couple. After considerable experimentation the length of each olive oil resistance was chosen as best at 0.5 cm. The notion was to steal as little energy from the oscillator circuit as possible for checking purposes and at the same time not to alter its mode of vibration or wave-length.

For changing the coupling readily the experimental arrangement shown in Fig. 7 was finally chosen. Cylindrical capacities 15 cm.

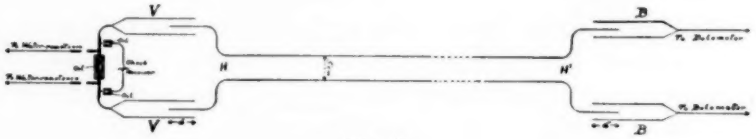

Fig. 7.

long by 3.5 cm. in diameter were attached both to the oscillator circuit and to the bolometer circuit. In this way the Lecher wires themselves were as free as possible at both ends. They were held in place at a distance of 5 cm. apart by supports of soft wood placed at HH' of the figure. To H' a tension of 4 kilograms was attached after the manner already described.

The degree of coupling was changed by changing the distance d to which the Lecher wires extended into the oscillator cylinders VV. Curves were taken with the Lecher wires protruding various distances into VV and BB but they served no useful purpose except to point out the best way of experimentation; for the type of curve materially altered as the distances d and d' increased much beyond 5 cm. Before describing further curves it seems well to illustrate the checking power of the check receiver and to show that in its new position it is uninfluenced by the location of the bridge. Fig. 8 demonstrates the latter point clearly enough, the check receiver readings being plotted against the bridge position for three different curves

chosen at random. Although the need for a check receiver is clearly seen one cannot possibly detect any sine nature of the curves such as Fig. 5 shows. The method of checking a bolometer reading was as follows. A preliminary experiment showed the location of the fundamental maximum for a given set of conditions. With the bridge at the position of this maximum and with galvanometer shunts adjusted for large deflections a set of from ten to twenty readings both of the bolometer and of the check receiver was taken. These readings were plotted against each other with the readings of the check receiver as abscissæ; a straight line was drawn through the points thus obtained. Then a regular curve was taken, the bridge being moved along the wires, consisting usually of about as many points as are shown in any of the curves of Fig. 8, both galvanometers being read of course. This usually took from one and a half to three hours. Then another set of ten or more readings was taken with the bridge again at the fundamental maximum. On account of temperature changes producing a slow unbalancing of the bolometer (shown by the wandering of the zero of the galvanometer) the straight line obtained from this last set of readings never coincided with the straight line obtained at the beginning of the curve. It usually lay several per cent. above it, though parallel to it. Trial had shown us that taking the ratio between the two galvanometer readings for any given bridge position would not be accurate enough, although better than the bolometer readings alone (see column 4, Table II.). If, for two successive readings with the bridge position constant the spark passed over a longer distance one time than the other, the ratio of the galvanometer readings should not necessarily be wholly constant. By increasing and decreasing the spark gap length we observed that the check re-

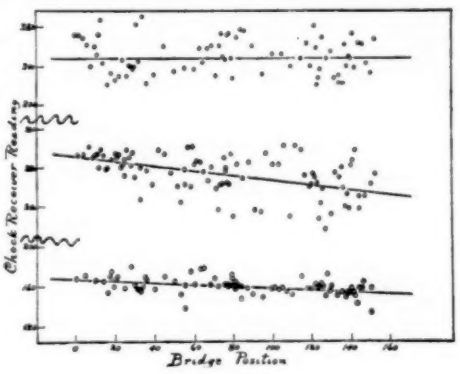

Fig. 8.

ceiver was always more strongly affected than the bolometer. If, however, we divided the bolometer reading for any given bridge position by its reading for the bridge at the position of the fundamental maximum for the same check receiver reading (making use of the straight line referred to above) we eliminated this error. The slow unbalancing of the bolometer was corrected for as follows. We added the per cent. of difference "x" between the two straight lines referred to above to 100 per cent. and plotted the two points 100, $100 + x$, with the mean zero of the bolometer galvanometer in each set as corresponding abscissa; these two points were joined by a straight line. For any given bridge position then we can get the

TABLE II.

Column 1.	Column 2.	Column 3.	Column 4.	Column 5.
Bridge Position.	Bolometer Reading.	Check Receiver Reading.	Ratio.	Relative Energy.
76	475	370	1.283	0.976
	449	341	1.318	0.972
79	201	287	0.700	0.485
	221	346	0.639	0.474
118	71	273	0.260	0.176
	77.5	320	0.242	0.175
149	32.8	380	0.086	0.066
	29.1	328	0.089	0.065
10	69	220	0.314	0.226
	75	260	0.289	0.224
88	51	240	0.212	0.158
	55	280	0.196	0.158
125	151	297	0.508	0.423
	135	248	0.554	0.423
149	111	232	0.478	0.351
	108	222	0.487	0.351

final correction factor by reading off the proper ordinates on this line. In this way we eliminate both oscillator deterioration and bolometer unbalancing entirely.[1] How nearly we have succeeded

[1] This bolometer unbalancing seems to be due to several things; among others may be mentioned direct radiation from the bodies of the observers and from the electric lamps used for illuminating the galvanometer-scales and the heat that comes from the electrical oscillations which on account of the cotton-wool packing immediately around the instrument cannot be readily equalized. Moreover, it is, of course, a function of the resistance in the auxiliary battery circuit and of the value of the galvanometer shunt.

in doing this is shown in column 5 of Table II., where the relative energy was obtained in the manner just indicated. The table contains random duplications for two different curves. The great superiority of column 5 over column 4 or column 2 (unchecked) will readily be admitted. So far as the oscillator is concerned we say without hesitation that we are able, by the employment of a check receiver situated as a shunt of high resistance across the spark gap, to eliminate all errors except an occasional error due to a mistake in reading a large deflection on a quick swing. A glance at Table II. will convince the reader that in general it is possible to duplicate any reading to a degree well within one per cent. Even for a badly worn oscillator one can duplicate to within two per cent., though it pays to repolish the oscillator occasionally. The results of Table II. and the curves yet to be spoken of in this paper were taken with the oscillator shown in Fig. 7 where the spark passed between two cylindrical hard steel rods each 5 cm. long and 3 mm. in diameter. At first we tried aluminium rods, after the manner of Schaefer and Laugwitz.[1] They worked better than the steel rods for the first few readings (perhaps twenty) but beyond that their action became more and more irregular and capricious and so they had to be abandoned. For the steel oscillator, on the other hand, it was no uncommon thing to take as many as six curves (say 600 readings) without repolishing. The oscillator was so constructed that the spark gap could readily be polished and cleaned by simply removing the rods from their ebonite support.

Effect of Changing the Coupling.

Using the steel oscillator and applying both corrections referred to above, the effect of changing the coupling between the oscillator and Lecher circuits was studied. To preserve the fundamental maximum fixed at a certain bridge position any change in the coupling was made at *both* ends of the Lecher system, though for some reasons it would have been better not to have changed the bolometer ends of the wires. Curves were taken for the following couplings, expressed as the distance in centimeters the Lecher wires

[1] Schaefer and Laugwitz, Ann. d. Phys., 23, p. 953, 1907. See also Laugwitz, Phys. Zeit., 8, p. 378, 1907.

were inserted into the cylindrical capacities at both ends: + 5 cm., + 3 cm., + 2 cm., +1 cm., 0 cm., − 1 cm., − 2 cm., − 3 cm. For the latter distance the coupling was so loose that the energy detected by the bolometer was very small, too small to make the results quite as reliable as for the other distances. Three of these curves are shown in Fig. 9, viz., + 2 cm., 0 cm., − 2 cm. One sees at a glance

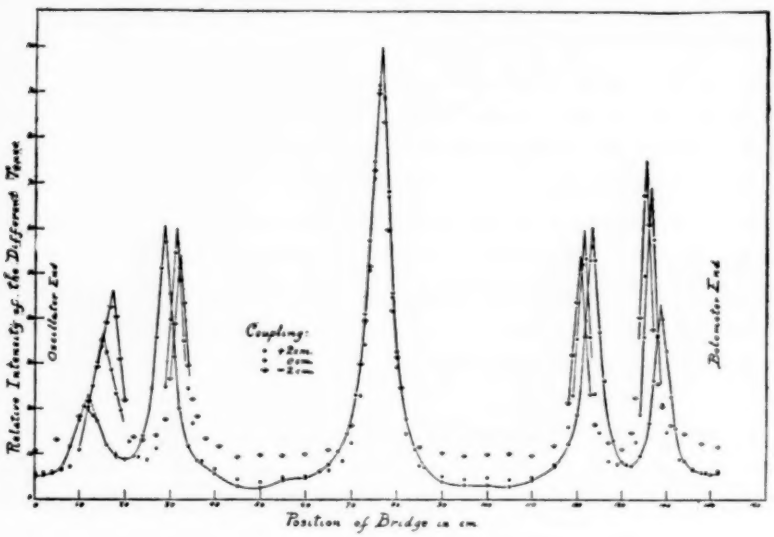

Fig. 9.

in contradistinction to Fig. 3, the practical absence of all third harmonics. The maxima are all drawn as sharp peaks in the figure, whereas in fact they are all rounding as shown in Fig. 10, where for a given case the fundamental maximum and the first harmonics are drawn to a larger scale. One sees at once from Fig. 10 that it makes no difference whether one chooses the peaks or the true maxima when comparing the various tones as to their relative intensities.[1] It should be noted also from the figure that the center

[1] For this reason we drew the curves of Fig. 9 as peaks for it was easier in this way to locate the maxima accurately. In fact for the data collected together in Tables III. and IV. each maximum was carefully drawn to a larger scale after all the corrections had been applied and, following Rubens, the center of gravity lines were drawn for locating the exact position of a maximum. When the center of gravity line was not vertical the position of the maximum was taken as the point of intersection of the actual curve with this center of gravity line drawn from the peak downwards. In this way any maximum is located accurately to within 1 mm. in general, though in certain cases we do not claim closer than a 2 mm. accuracy.

of gravity line of each maximum is vertical. It will be shown later that when this is not the case it reveals two maxima in one, the extra one being due to the oscillator.

If we study Fig. 9 we note the following points. Figured from the fundamental at 76.4 cm. the semi-internodal spaces for the first harmonics are greater on the left than on the right of the figure, the disparity growing less as the coupling grows looser. The same

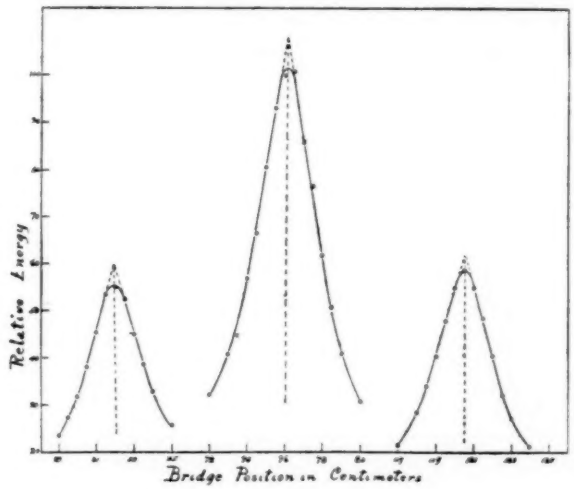

Fig. 10.

is true for the internodal distances for the second harmonics, only to a greater extent. This is more clearly seen in the two lower curves of Fig. 11, in which the data for several curves not shown in Fig. 9 are included. We see from these curves that the lack of symmetry in the internodal spaces disappears for the looser couplings, for practical purposes vanishing at the coupling -1 cm. We see, moreover, from Fig. 9 that the two first harmonics decrease, but remain equal to each other as the coupling is changed, a thing they should do. For the second harmonics we notice that as the coupling gets looser, the two second harmonics (omitting the central second which is concealed in the fundamental and hence cannot be argued about) increase in intensity, but the one nearer the bolometer end is always the larger; for the looser couplings it overtops the first harmonics. If we examine closely the second harmonic near

the oscillator end we notice that it is much broader at the base in proportion to the other maxima than it ought to be. Moreover, its center of gravity line is usually distinctly out of the vertical.

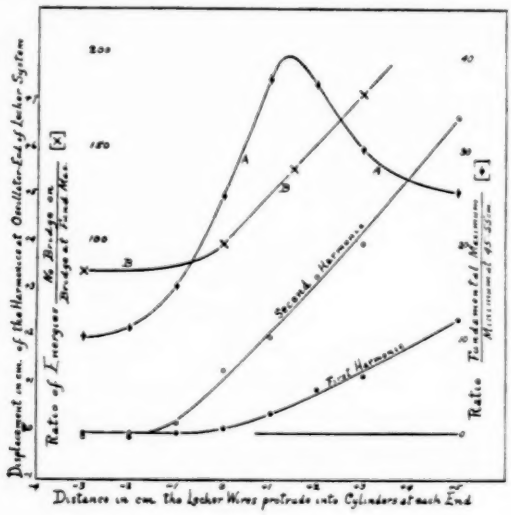

Fig. 11.

This shows two maxima run together into one and we found by experiment in certain cases that the true position of either one could not be determined accurately. This gives us a clue also to the very high value of the second harmonic near the bolometer end as the coupling gets looser. The fundamental vibration of the oscillator falls in more fully with this second harmonic and hence greatly increases its intensity. However, the oscillator vibration is still somewhat longer than this free second, for the slope of the fundamental on the oscillator side is less steep than on the bolometer side, while both the oscillator swing and the free second appear, as has been said, in the broad maximum near the oscillator end, the former lying closer to the oscillator by reason of its greater length. For this reason the internodal spaces for the seconds are even more unsymmetrical than for the firsts as Fig. 11 plainly shows. Moreover, the presence of two maxima in one makes it harder to determine the actual top of the double maximum, hence in Fig. 11 the points for the second harmonics lie further from the smooth

curve than for the firsts. For the latter it is seen that the greattes deviation of any point from the curve is 1 mm.

Another thing should be said about Fig. 9. As the coupling became looser we saw that the first harmonics were pulled down in intensity while the seconds were pulled up. This is undoubtedly partly due to this oscillator vibration. That this is so is shown clearly in Curve *I*, Fig. 12, where for a longer Lecher system than

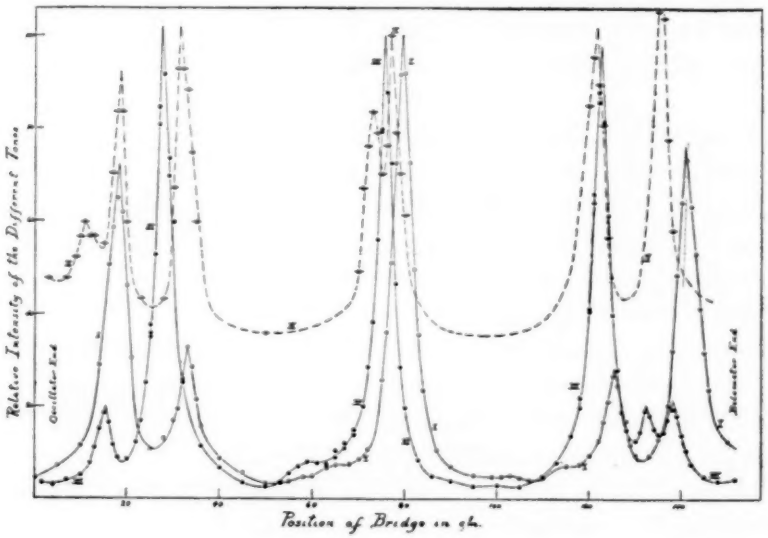

Fig. 12.

those illustrated in Fig. 9 the coupling was as follows: vibrator end − 1 cm., bolometer end + 3 cm. Here the oscillator vibration was in exact unison with the free second harmonic, hence both of these harmonics are very high. The first harmonics at 33 and 125 cm. are correspondingly low. Without changing the actual length of the Lecher wires we then changed the coupling to − 1 cm. at the bolometer end leaving the coupling at the oscillator end as it was. In this way, since the effective length of the parallel wires was lessened, it ought to be possible to throw the free second out of tune with the oscillator vibration and hence they ought to stand out separately. That this was accomplished is shown in Curve *II*, Fig. 12. The oscillator swing comes in at 11, 73 and 135.5 cm.

with an internodal space of 62 cm. The free second appears at 18.5, 77 and 135.5 cm. giving an internodal space of 58.5 cm. Both vibrations occur together at 135.5 cm. and make the maximum very high (one and a half times the fundamental). For Curve *I* both oscillations came in at 18.2, 79.5 and 140.8 cm. with an internodal space of 61.3 cm., in substantial agreement with the oscillator internodal space of Curve *II*.[1]

That the oscillator vibration can be made to swing in with some other harmonic is shown in Curve *III* of Fig. 12. This curve was taken earlier with a different oscillator of somewhat greater length, though the same cylindrical capacities were used as for the other curves. The coupling was + 1 cm. at both ends. In this curve there are two fundamental oscillations present, one at 27.8 and 122.3 cm., the other at 59 and 132.5 cm.,[2] the first one falling in with the free first harmonic to make it of abnormal intensity. Here we notice that when the firsts are very high the seconds at 15.4 and 137 are abnormally low.[3]

Referring again to Fig. 11 we saw that as the coupling at both ends got looser and looser the internodal spaces on the two sides of the fundamental became more nearly equal until for a very loose coupling (− 1 cm. or less say) the equality is exact. If from the two lower curves of Fig. 11 we were to calculate the fundamental wave-length, we would obtain curves entirely similar in nature to the curves of Fig. 6 of Blake and Ruppersberg. It is accordingly

[1] In all the curves of Fig. 12 no corrections were applied. The bolometer readings, reduced to 100 for the fundamental, alone are plotted. Hence the maxima are not located with great accuracy.

[2] These internodal spaces of 73.5 cm. and 94.5 cm. for the oscillator vibrations make the half wave-length of the oscillator when isolated 84.6 cm. These figures are checked thus; adding 47.2 to 122.3 gives as the end of the wire including the end capacity 169.5 cm.; subtracting 36.8 from 169.5 gives 132.7 cm., in agreement with 132.5 cm. Now the length of this oscillator up to the cylindrical capacities was 35.6 cm. This makes the equivalent length of wire for each cylindrical capacity 24.5 cm. or roughly 1.5 times its natural length.

[3] We are not entirely clear why apparently the intensifying of one harmonic by the oscillator vibration should lower the intensity of a neighboring harmonic. The fact that merely changing the coupling at the bolometer end from + 3 cm. to − 1 cm. changed Curve *I*, Fig. 12, into Curve *II* of the same figure, seems to point to the fact that the nature of this coupling plays an important part in determining the relative intensities of neighboring harmonics.

plain that the closeness of the coupling in their work was the cause of their overtones not being harmonic.

A glance at Fig. 9 shows that as the coupling gets looser the ratio of maximum to minimum decreases. However, for some of the curves not shown (viz., + 3 cm., + 5 cm.) as the coupling gets closer this ratio also decreases. All the data are collected together into Curve *A* of Fig. 11. We see that this ratio attains a maximum for the coupling + 1.4 cm. Its value is 40 to 1. This is roughly four times as good as Rubens got and one third as good as the value obtained by Blake and Ruppersberg.

Curve *B* of Fig. 11 was obtained by carefully comparing the bolometer readings with no bridge on the Lecher system against those with a single bridge placed at the fundamental maximum, the coupling being changed symmetrically at both ends. For close coupling there is more energy detected at the bolometer for no bridge on the parallel wires than for a bridge placed at the fundamental maximum and the closer the coupling the greater this energy. For couplings less than 0 cm. the reverse is true. It is interesting to note that for this particular coupling of 0 cm. the readings with and without a bridge are identical. It seems, perhaps, unprofitable at this time to speculate as to the meaning of this curve *B*. One might expect that all the tones ought to be present on the parallel wires when there is no bridge on them. If this were true the reading for no bridge ought to be roughly 2.3 times the reading for a bridge at the fundamental maximum. It should be borne in mind, however, that the free vibrations are only maintained in the Lecher system (so far as our detecting devices register) by a steady in-pour of energy at the oscillator end of the system. Very likely this plays a part that must yet be taken into account. In this respect the case is different from that of pulling a pendulum back and then letting go.

Comparison of Theory with Experiment.

An attempt was made, from the curves of Fig. 9 and from the five other curves not there shown but taken with equal care, to compare the results with the theory outlined by Kirchhoff and fully developed by Abraham.[1] How well the attempt succeeded is shown

[1] Abraham, Theorie der Elektrizitat, Vol. 1, 2d ed., page 347.

TABLE III.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Coupling cms. Insert of Wires.	Tone.	Position on Wire.	Actual End of Lecher Wire.	End of Wire Including λ_0'/λ'.	λ_0'/λ' (cms.).	l	Method for λ.	λ	$\alpha = \lambda l/\lambda_0$	$\alpha = \xi \tan \xi$	Per Cent. Variation.	$\xi = 2\pi \frac{l}{\lambda}$	γ ($\tan \gamma = \frac{\gamma}{2\pi \lambda_0 \lambda \lambda'}$)	$\xi + \gamma = \pi/2$.	Total Actual Length of Wire, l_0	Capacity at Oscillator End.	$\frac{\lambda_0}{l_0}$ = wave-length / wire-length
+5	Fund.	76.3	168.4	174.2	5.8	92.1	A	391.8	15.88	15.63	1.6	84° 36′	5° 19′	89° 54′	181.3	8.8	2.16
	1st har.	125.4				43.0	A	196.4	74.20	69.32	6.0	78° 46′ 54″	10° 29′	88° 47′			
	1st har.	25.0				143.4	B	205.2	24.72	13.15	47.0	71° 32′ 24″	10° 4′	81° 36′			
	2d har.	141.6				26.8	B	130.6	4.64	4.46	4.0	73° 51′ 15″	15° 36′ 30″	90° 17′			
	2d har.	4.2				164.2	B	144.2	28.31	12.64	50.0	60° 30′	11° 58′	72° 28′			
+3	Fund.	76.6	166.4	171.2	4.8	89.8	A	378.3	18.71	18.66	1.5	85° 25′ 48″	4° 33′ 30″	90° 0′	177.4	6.8	2.14
	1st har.	124.1				42.3	A	190.0	8.82	7.92	11.0	79° 56′	9° 0′ 30″	88° 57′			
	1st har.	27.8				138.6	B	195.2	28.87	17.66	40.0	75° 48′ 36″	8° 47′ 30″	82° 37′			
	2d har.	139.6				26.8	A	126.0	5.58	5.58	0.0	76° 32′ 50″	13° 29′ 20″	90° 1′			
	2d har.	9.7				156.7	B	133.8	32.65	12.98	62.0	60° 31′ 12″	12° 22′ 30″	72° 45′			
+2	Fund.	76.4	165.4	170.2	4.8	89.0	A	374.4	18.54	19.20	−3.5	85° 34′ 40″	4° 13′ 30″	89° 48′	175.5	6.4	2.14
	1st har.	28.7				136.7	C	189.6	28.48	24.33	14.0	79° 28′ 20″	9° 2′ 20″	88° 31′			
	1st har.	28.7				136.7	B	190.8	28.48	20.64	24+	77° 48′ "	11° 12′ 20″	89° 0′			
	1st har.	123.5				41.9	D	186.4	8.72	8.81	−1.1	80° 54′	9° 12′ 40″	90° 7′			
	2d har.	11.0				154.4	B	130.4	37.16	16.82	55.0	66° 9′	13° 1′ 20″	79° 22′			
	2d har.	76.4				89.0	A	124.8	18.54	18.94	2.5	76° 42′	13° 35′	90° 17′			
	2d har.	138.8				26.6	A	124.8	5.54	5.65	2.0	76° 42′ 30″	13° 35′	90° 17′			
+1	Fund.	76.4	164.4	168.5	4.1	88.0	A	368.8	21.47	21.26	1.0	85° 57′ 40″	4° 0′	89° 58′	173.6	6.8	2.12
	1st har.	29.9				134.5	C	185.2	32.80	30.04	9.0	81° 21′ 24″	7° 51′	89° 15′			
	2d har.	76.4				88.0	A	122.8	21.47	20.94	2.5	77° 52′	11° 52′	89° 42′			

0	Fund.	76.45	163.4	166.5	3.10	87+	A	360.4	28.06	27.79	1.4	86° 53′	3° 5′ 40″	89° 59′	171.6	5.5	2.10
	1st har.	31.45				132.0	A	180.1	42.58	42.44	0.3	83° 48′ 10″	6° 10′ 20″	89° 58′			
	1st har.	31.45				132.0	C	180.0	42.58	43.11	−1.3	83° 54′	6° 10′ 30″	90° 4′			
	1st har.	121.5				41.9	D	180.2	13.51	13.42	0.6	83° 46′ 48″	6° 10′ 30″	89° 58′			
	2d har.	15.4				148.0	B	122.0	47.74	31.99	32+	76° 36′	9° 4′ 10″	85° 40′			
	2d har.	76.45				87+	A	120.1	28.06	28.00	0.25	80° 46′	9° 12′ 20″	89° 58′			
	2d har.	136.50				26.9	D	120.1	8.67	8.49	2.1	80° 36′	9° 12′ 40″	89° 48′			
−1	Fund.	76.4	162.4	165.6	3.20	86.3	A	356.8	26.25	26.15	0.4	86° 41′	3° 13′ 30″	89° 56′	169.5	5.7	2.10
	1st har.	31.8				130.6	B	178.4	40.75	40.40	0.85	83° 28′	6° 25′ 40″	89° 54′			
	2d har.	76.4				86.3	A	118.8	26.25	26.64	−1.4	80° 20′	9° 36′ 20″	89° 57′			
	2d har.	16.8				145.6	B	119.0	45.50	45.10	0.9	80° 21′	9° 35′ 20″	89° 57′			
−2	Fund.	67.4	162.4	164.9	2.5	86.0	A	354.0	34.40	34.42	−0.01	87° 27′ 45″	2° 32′ 30″	90° 10′	169.5	5.0	2.09
	1st har.	32.2				130.2	B	176.8	52.08	51.93	0.3	84° 54′ 44″	5° 4′ 20″	89° 59′			
	1st har.	120.5				41.9	C	176.6	18.38	18.58	−1.1	85° 24′ 54″	5° 3′	90° 27′			
	2d har.	17.4				145.0	B	118.0	58.02	58.08	−0.1	80° 26′	7° 34′	90° 0′			
	2d har.	135.4				27.0	D	118.0	10.80	10.74	0.6	82° 22′ 40″	7° 35′	89° 58′			
−3	Fund.	76.1	161.4	163.8	2.4	85.3	A	350.8	35.54	35.48	0.02	87° 32′ 6″	2° 27′ 40″	90° 0′	168.5	4.5	2.08
	1st har.	32.3				129.1	B	175.4	53.79	52.89	1.8	84° 59′ 40″	4° 54′ 50″	89° 55′			
	1st har.	120.0				41.4	C	175.6	17.20	16.60	3.6	84° 56′	4° 54′ 30″	89° 50′			
	2d har.	17.7				143.7	B	116.8	61.60	59.90	3.0	82° 51′	7° 21′ 20″	90° 11′			
	2d har.	134.6				26.8	D	117.0	11.16	10.90	3.5	82° 26′	7° 41′	90° 7′			

A = wave-length calculated from the interval between the fundamental and the harmonic at *bolometer* end.

B = wave-length calculated from the interval between the fundamental and the harmonic at *oscillator* end.

C = wave-length calculated from the ***internodal*** space for a given harmonic.

D = wave-length calculated from the ***quarter wave*** distance of the harmonic from the corrected end of Lecher wire.

in Tables III. and IV. Both tables are self-explanatory. In order to see whether the maxima of the curves fall at their theoretical positions columns 10 and 11 of Table III. are to be compared, the percentage variation being given in column 12. It is seen from the

TABLE IV.

Distribution of Energy. [*Cylindrical Capacities.*] *Potential Difference* $= \Phi_1 - \Phi_2 = 2\frac{|A|}{K}\cos\left(\frac{vx}{w} - \gamma\right)\cdot\cos(vt) \propto \sin\left[\frac{\pi}{2}\left(\frac{1}{n+1}\right) - 2\gamma\right]$. *Phase Change* $= 2\gamma$ (where $\tan\gamma = \frac{v}{w}\cdot\frac{K_0}{K} = \frac{2\pi K_0}{\lambda K}$). ($n$ = no. of overtone.)

Coupling (cms.).	$\frac{K_0}{K}$ (cms.)	l (cms.).	λ (cms.).	2γ	Tone.	Intensity.		
						Theory (Per Cent.)	Experimental (Per Cent.)	Diff.
−2	2.5	86	354	5° 5′	Fund.	100	100	——
					1st har.	64.1	58.1	− 6.0
					2d har.	42.1	79.0	+36.9
+1	4.1	88	368.8	8° 0′	Fund.	100	100	——
					1st har.	60.2	62.8	+ 2.6
					2d har.	37.5	62.8	+25.3
+2	4.8	89	374.4	8° 27′	Fund.	100	100	——
					1st har.	60.2	61	− 0.8
					2d har.	37.1	43.5	+ 6.4
+3	4.8	89.8	378.3	9° 7′	Fund.	100	100	——
					1st har.	60.35	60	−0.35
					2d har.	36.70	38	+1.30
+5	5.8	92.1	391.8	10° 28′	Fund.	100	100	——
					1st har.	57	69.2	+12.2
					2d har.	33.4	34.6	+ 1.2

table that here the agreement is entirely satisfactory for *loose couplings*.[1] For the couplings − 1 cm. and − 2 cm. one can say that there is agreement to within 1 per cent. As the coupling gets closer the agreement is less good until for the closest couplings (+ 3 cm. and + 5 cm.) the disagreement for the maxima near the oscillator reaches values around 50 per cent. We regard this as a complete experimental verification of the truth of the Kirchhoff-Abraham generalization of the Thomson formula

[1] It should be borne in mind that for the −3 cm. coupling the energy available was too small to make accurate work possible.

$$\frac{2\pi l}{\lambda} \tan \frac{2\pi l}{\lambda} = \frac{Kl}{K_0}.$$

So far as we are aware this verification up till now has been lacking. It is to be said, of course, that the formula has been proven to hold only for the case where the end-capacity is small in comparison to the total capacity of the discharge wire. The reverse case, the Thomson formula, has been verified by many investigators. The general case, viz., when the capacities of the condenser and discharge wire are comparable in value, remains to be verified. We have assigned ourselves the task of attempting its verification and hope to be able to make a report in the near future.

It is of course not to be expected that there should be good agreement between theory and experiment for the *close* couplings. For the theory takes no account of the mutual interaction of the oscillator and Lecher circuits. In view of the importance of the subject both from the theoretical and practical standpoints some of the mathematical physicists might find it desirable to consider the effect of coupling upon the free vibrations of such a system. Furthermore, agreement between theory and experiment is not to be expected as to the relative intensities of the various maxima. For the theory assumes the entire absence of oscillator vibrations. In no case, so far, have we been able to avoid them entirely. Experiments are now in progress where by employing a very long oscillator we hope to free the Lecher system from the oscillator vibrations. For the case that seemed the most promising, viz., the right half of the + 3 cm. curve we have recorded the comparison in Table IV. The agreement is satisfactory. However, the figures for the − 2, + 1, + 2, and + 5 cm. curves attest that there are two causes present in our experiments tending to vary the relative intensities of the harmonics, neither of which the theory takes into account; namely, the presence of the oscillator vibrations and the effect of coupling at both ends of the Lecher wires. These two causes are to be differentiated from each other. For the figures given in the table, which are only for the harmonics near the bolometer end, the coupling at this end as it gets closer (*e. g.*, + 5 cm.) raises the first harmonic above its theoretical value. For the loose

couplings (*e. g.*, -2 cm.) the reverse is true, but superimposed upon this effect is the swinging in of the oscillator vibration in tune with the second harmonic to raise it far above its normal value. The figures for all the curves not shown in the table bear out this idea.

Referring again to Table III. it should be remarked that since both α and $\xi \tan \xi$ involve l it is plain that the per cent. of variation between theory and experiment is but little affected by a mistake of a few millimeters in determining[1] the actual end of the wire. It is, of course, difficult to determine accurately the true reading of K_0/K. If we plot the values as given in column 6 against the

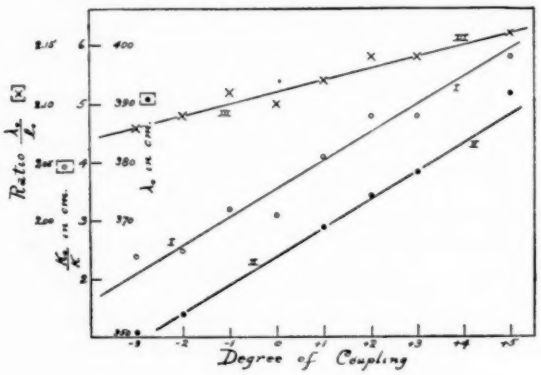

Fig. 13.

couplings we obtain Curve *I* of Fig. 13. Although the points do not fit the curve very closely the change in capacity seems to be a linear function of the extent to which the Lecher wires extend into the cylinders. Curve *II* of the same figure shows the change in wave-length as the wires were shortened. In both these curves it should be remembered that a change of one or two millimeters in locating a given maximum or the actual end of the wire could readily account for the variations from the curves shown.[2] We have seen

[1] The actual end of the wires was determined within 0.5 mm. for the coupling -3 cm., the other values being obtained by adding the amount clipped off of the bolometer end as we lessened the coupling. No great care was used in doing this cutting. The amount cut at the two ends was generally though not always the same.

[2] As a matter of fact the maxima were located more accurately than the measurements of the linear dimensions of the system would warrant. We were not aware of the need for the closest measurement until after these experiments were completed

that a close coupling displaces the harmonics near the oscillator toward the oscillator. For a coupling as close as + 5 cm.[1] it is very probable that the fundamental itself is also somewhat displaced in the same direction. This would account for the fact that on the wave-length curve of Fig. 13 the + 5 cm. point is too high.

The total length of the Lecher wires is given in column 16 of Table III. If we add to this length twice the value of K_0/K and multiply the result by 2, in every case we obtain a figure which is several centimeters short of the value for λ_0 given in column 9. Now physically the capacities at the two ends of the Lecher wires were always identical. The only possible interpretation of this discrepancy is this, it seems to us—electrically there is a real difference in value between the capacities at the two ends in spite of their identical geometrical configuration. The values of the end-capacity at the oscillator end are given in column 17 of the table. In general they are from 2 to 3 cm. higher than the corresponding capacities at the bolometer end of the system. Nor can this difference be materially altered by the "juggling" of the points of Curve *I*, Fig. 13, to fit the curve. In attempting an interpretation of this difference in the end capacities one should remember that there is a constant in-pour of energy at the oscillator end and an out-pour of energy at the bolometer end. This would necessarily introduce phase differences at the two ends. Indeed, the essential difference between the facts of our experiments and the theory lies here, it seems to us. Theory calls for a permanent train of waves continually reflected from end to end of the parallel wires.[2] In our experiments, to account for all the facts, one would have to calculate the phase relations between the incoming and reflected waves at the oscillator end of the Lecher system and between the outgoing and reflected waves at the bolometer end of the system. The original

and the comparison with theory was undertaken. The figures in column 4 are accurate only to within 2 mm. due to a lengthening of the Lecher wires (unfortunately they were soft copper wires) under tension. We have no means of correcting this, however, and it certainly can affect the arguments or the conclusions arrived at not at all.

[1] The terms "close" and "loose" couplings in this paper are relative terms only. It is probable that even the closest coupling we used would be called "loose" in wireless telegraphy.

[2] We are safe, we think, in assuming with MacDonald (Electric Waves, p. 82) that the train of waves is permanent except for radiation at the ends.

notion of Professor Rubens was to have the detecting instrument steal but an inappreciable fraction of the energy from the swinging Lecher system. This is undoubtedly correct. However, we ought to expect that as the coupling gets looser the difference between the two end capacities would tend to vanish. It seems from comparing columns 6 and 17 of Table III. that this is the case but more accurate measurement would be necessary to determine this.

If we plot the ratio between the fundamental wave-lengths, λ_0, to the total actual wire lengths, l_0, for the different couplings we obtain Curve *III*, Fig. 13. For the loosest coupling the ratio is 2.08, increasing in a linear ratio with the coupling. Extrapolated backward this curve cuts the horizontal axis 2.00 for the coupling $-$ 11.5 cm. Now for the coupling $-$ 3 cm. the energy available at the bolometer end was as small as our apparatus would detect. Great increases in the sensibility of the detecting instruments would have to be attained before this limiting ratio 2.00 could ever be reached. The question of the true value of this ratio in a given case and the factors that control it is very important. We regard it as unsettled. It demands a special investigation. It will be conceded we think that a greater degree of care has never been used in work on electric waves than we have used in these experiments. Curve *III* shows that the ratio can vary with the conditions. We mention this in the hope that other experimenters in this field will stop wasting time working on this question using the earlier crude methods.

When in the work of Blake and Ruppersberg it was stated that our experiments would show that there was always an "end-correction" of four per cent., it was thought that Curve *I* of Fig. 13 sloped off asymptotically toward the X-axis for looser couplings. Careful revision of the data shows that a straight line would fit the points as well as a curve however. We still have the feeling that such an end-correction is present even in an absolutely isolated Lecher system. But we are not able at present to insist on this. We must investigate further. Nor would the presence of this end-correction mean necessarily radiation taking place from the free ends. We can conceive that some of the energy might swing past the free end before reflection occurs and yet get back again instead of being lost to the system by radiation.

SUMMARY.

1. We have shown by these experiments how it is possible to get the free vibrations of a Lecher system by using a Lecher oscillator with suitable water resistances and air-gaps between the induction coil and the vibrator spark-gap. It was proven that in this case the frequencies were in the ratio of the natural numbers 1, 2, 3, 4, etc., while in the case of the Lecher circuit closed at the end (Blondlot type) the frequencies present bear the ratios 1 : 3 : 5 : 7, etc.[1]

2. The effect of changing the coupling between the various circuits was studied and it was found that for a loose coupling the tones present were strictly harmonic. When this was the case it was found possible to verify the Kirchhoff-Abraham generalization of the Thomson formula for a discharge circuit to within one per cent. This was accomplished only by employing a check receiver and introducing all possible refinements of experimental methods.

3. The effect of changing the distance between the Lecher wires was studied and it was found to introduce complications as this distance and hence the bridge lengths became appreciable in amount in comparison to the length of the Lecher circuit, a result to be expected. The best set of free vibrations was obtained when the distance between the Lecher wires was 1.6 per cent. of their own length.

4. Our experiments were compared with the theory of free vibrations completely developed by Abraham and they were found to differ from the theory because of two conditions which the theory does not allow for, viz., the presence of oscillator vibrations on the Lecher circuit and the necessary proximity of the source of energy supply and of the means of detection of the vibrations.

5. When the coupling between the oscillator and Lecher circuits was close two fundamental oscillator vibrations were usually present. It was found that the oscillator vibration could be made to superpose itself upon any given harmonic to make it of abnormal intensity. No overtone of the oscillator seemed to be present.

[1] The consistency (?) of the usual notation is here clearly shown. It is customary in alternating current work to say that only the odd harmonics are present, or in other words to *include* the fundamental as one of the harmonics. The same is true for closed organ pipes. For open organ pipes on the other hand we *exclude* the fundamental from the list of harmonics, for we say the octave of the fundamental is the first harmonic.

6. For the best set of free vibrations the ratio of maximum to minimum was 40 to 1. This was obtained when the coupling at both ends of the Lecher circuit was + 1.4 cm. in arbitrary units for an unusual type of coupling.

7. The ratio of wave-length to wire length was found to vary with the coupling, ranging from 2.16 to 2.08, the last figure in agreement with the result of Blake and Ruppersberg.

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A COMPARISON OF THEORETICAL AND OBSERVED EQUILIBRIUM TEMPERATURES IN FOG CHAMBERS.

By Edgar K. Chapman.

THE first attempt to make a direct determination of the temperature existing the instant after expansion in a Wilson fog chamber seems to have been made by R. A. Millikan[1] in connection with work on the determination of *e*.

He found that if the temperature fell at all to the theoretical value it returned almost instantly to room temperature.

Further experiments by Millikan, Chapman and Moody[2] showed that this exceedingly rapid rise in temperature after the expansion was due to the rapid inflow of heat from the metal electrodes.

The present experiments were undertaken at the suggestion of Professor Millikan to determine whether, in a fog chamber in which such an inflow of heat was not possible, the actual equilibrium temperature reached in an expansion would agree with the value given by C. T. R. Wilson's method of computing this temperature.[3]

The experimental determination was made as follows: one junction of a Cu-Fe thermo-couple of mil wire was introduced into the middle of a large carboy of 100 liters capacity containing in addition to air, the liquid and its saturated vapor. This couple was connected in series with a sensitive galvanometer. The other junction was kept at a constant temperature by means of a large water bath in which the carboy was also immersed. A battery of constant E.M.F. was connected in series with two resistances, one of approximately 100,000 ohms, the other of a value which varied from one to ten ohms. The thermo-couple was connected to the terminals of this latter resistance so as to form a potentiometer system. The pressure within the carboy was then increased to any desired amount

[1] Phil. Mag., Vol. 19, pp. 214, 1910.

[2] Phys. Rev., Vol. 30, pp. 286.

[3] Phil. Trans., A, pp. 209, 1907, also J. J. Thomson, Phil. Mag., Vol. XLVI., pp. 538, 1898, and "Conduction of Electricity through Gases," 1906.

by means of a bicycle pump and the system was left standing until the temperature of the bath had been attained. A large valve was then opened so as to allow the pressure to fall to that of the room. When the keys in both circuits were closed simultaneously the thermo-electric current was manifested by the deflection of the galvanometer. The value of the variable resistance was then changed and the operation repeated until the E.M.F. of the couple was balanced by the P.D. across this resistance.

The couple was then graduated and a *temperature-P.D.* curve drawn so that the temperature after expansion could be read directly from this curve.

The final form of the theoretical equations used by J. J. Thomson for computing these temperatures is

$$\rho = \frac{\rho'}{x} - \frac{C_v}{L} \frac{.00129}{x} \frac{273}{273 + T} \frac{p}{760} (t - t_2).$$

T is the temperature of the saturated vapor before expansion.

ρ' is the vapor density of the saturated vapor before expansion.

x is the ratio of the final volume of the gas to its original volume.

p is the original pressure.

t_2 is the temperature to which the gas falls by adiabatic expansion.

t is the equilibrium temperature of the gas, *i. e.*, the temperature to which it rises from t_2 because of the condensation of the vapor, and ρ is the vapor density at the temperature t. Thus ρ is a known function of t, and the solution consists in substituting values for t until one is found which gives ρ its known value.

After considerable work with this equation, it was found that the value given by the thermo-couple did not agree with the computed value, the former being constantly higher than the latter.

A consideration of the origin of the above theoretical equation convinced the author that the value of x given by Thomson in the form

$$x = \frac{V_2}{V_1} = \frac{P_1}{P_2} = \frac{B + p - \pi}{B - \pi}$$

should instead take the form

$$x = \frac{V_2}{V_1} = \frac{P_1}{P_2} = \frac{B + p - \pi}{B - \pi_{t_2}},$$

in which B = barometric pressure, p = difference in levels of manometer before and after expansion, π = vapor density at the temperature of the experiment and π_{t_2} = vapor density at the temperature t_2.

Since the pressure of the air after expansion is $B - \pi_{t_2}$ instead of $B - \pi$ the latter form is obviously correct and the difference between π and π_{t_2} in experiments of this kind is so great that there is a considerable difference between the results of the two formulæ.

When this correction in Thomson's formula was made the experimental and theoretical results were found to be in complete accord as the following table shows:

T	P_1	P_2	t (computed).	t' (observed).	$t-t'$
21.9	90.15	73.35	13.91	13.96	−.05
21.9	93.95	73.35	11.91	11.96	−.05
21.9	98.05	73.35	9.	9.98	−.98
21.9	102.1	73.35	7.5	8.	−.5
22.2	89.2	72.55	14.26	14.44	−.18
22.2	84.85	72.55	16.5	16.73	−.27
22.1	80.97	72.51	18.01	18.12	−.11
22.	76.73	72.58	20.31	20.01	+.30
20.95	78.15	73.65	18.82	18.99	−.17
21.85	82.46	73.56	17.65	17.76	−.22
21.85	86.06	73.56	16.	15.88	+.12
21.85	90.26	73.52	13.84	13.93	−.09
28.7	80.17	71.62	25.25	24.72	+.53
28.5	84.59	71.65	23.1	22.53	+.57
28.5	90.05	71.65	20.85	20.54	+.31
28.25	94.94	71.69	18.21	18.31	−.10
28.15	99.31	71.71	16.20	16.23	−.03
20.5	88.60	71.75	11.80	12.26	−.46

Average difference between the thermo-couple and computed values is .05° C.

The air was then saturated with alcohol vapor with the following results.

T	P_1	P_2	t (computed).	t' (observed).	$t-t'$
20.8	75.18	71.1	19.03	18.81	.22
20.45	81.66	72.61	16.65	16.47	.18
20.45	87.65	73.31	14.50	14.48	.02
20.6	94.16	74.	12.16	12.64	−.48

The results show that the thermo-couple takes up the temperature completely, the slight error of .05° C. being in the direction expected and practically nil.

Further in no case is there any evidence that the temperature falls below the equilibrium temperature. The heat of condensation counteracts the lowering of the temperature due to the adiabatic expansion of the gas. If this were not true, the thermo-couple would certainly indicate it, for the difference between the lowest temperature and the equilibrium temperature is in some cases more than 20° C.

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June, 1910.

SPARK LENGTH, POTENTIAL AND FREQUENCY OF OSCILLATION: THE "LAG EFFECT" IN ELECTRIC DISCHARGE.

By J. C. Hubbard.

Introduction.

THE spark potential for a given spark length is ordinarily defined as the greatest potential which can be applied to the spark gap for an indefinitely long time without causing the discharge to take place. The usual method of measuring spark potentials has accordingly been that of slowly increasing the potential, keeping the spark length constant, or of slowly diminishing the latter while the potential remains constant, until the discharge occurs. Extensive work has been done on the relation between spark length and potential for steady potentials, an admirable summary of which may be found in Sir J. J. Thomson's Conduction of Electricity through Gases (second edition). The study of short sparks has been especially prominent in recent years owing to the bearing of the phenomena upon the theory of ionization.[1]

It has long been known that a potential greater than the spark potential as defined above may be applied for a short time without producing discharge, especially if the gas be dry and free of dust. This effect has been called the "lag" of the spark, or the lag effect, and on it there has been much experimental work and discussion. Jaumann[2] pointed out some time ago that the time of lag is the interval necessary for some agency to convert the gas from an insulator into a conductor. It has been found that the presence of moisture, or the effect of such agents as ultra-violet light and Roentgen rays, in short, that the introduction by any agency of ions into the field between the electrodes, reduces the time of lag; though the ultimate discharge potential is not much affected.

[1] Conduction of Electricity through Gases, pp. 455–460. See also E. H. Williams, Phys. Rev., 31, pp. 216–240, 1910.

[2] Jaumann, Wied. Ann., 55, p. 656.

No very definite attempt seems so far to have been made to study quantitatively the lag effect. A promising method consists in applying electric oscillations of known amplitude and frequency to the spark gap. In a previous communication of mine to this journal[1] very positive indication was found that for sparks produced by an oscillating potential the spark length is a function not only of the maximum potential but also of the frequency of oscillation. The relation found was such that for very slow oscillations the spark potential approached the value for steady potentials, while with increasing frequency and constant spark gap the spark potentials became systematically higher. The work was not undertaken primarily with the object of studying the lag effect, and, as the spark gap in this case was at the break of an inductive circuit where complications due to the motions of parts might arise, in so far as it relates to the lag effect it is not to be considered of final value. There appeared almost simultaneously some interesting experiments by J. Algermissen[2] on the relation of spark length and potential for rapid oscillations of potential leading to similar results. The oscillations were produced in a system containing a spark gap by induction from a neighboring circuit. Sparks up to 2 cm. in length were studied, and complications arising from the length of spark being large in comparison to the radius of spark electrodes were introduced. The result was unmistakable, however, that as the frequency is increased the spark potential is increased for a given spark length.

The present study of alternating spark potentials makes use of a new method designed to give values of the potential and frequency under perfect control, and presents results of observation of a large number of cases together with some general conclusions.

THE SOURCE OF POTENTIAL.

As a source of potential in the present work is used the oscillations set up in a circuit containing inductance and capacity when the initial current is interrupted. The conditions for breaking such a circuit without producing a spark at the break have been given in

[1] J. C. Hubbard, PHYS. REV., 22, pp. 129–158, March, 1906.
[2] J. Algermissen, Ann. der Phys. (4), 19, p. 1016, April, 1906.

my paper referred to above. In brief, if the speed of separation of the contacts exceed a certain critical value, called the velocity of break, no spark will be produced on breaking the circuit. This critical velocity was found to be proportional to the frequency and to increase almost linearly with the maximum potential, the effect of damping being negligible. Making use of a circuit breaker operated under the proper conditions it is possible, within the limits set by the attainable velocity of break, to secure oscillations of any desired frequency and initial amplitude.

Method and Apparatus.

The electrical system is shown diagrammatically in Fig. 1. The principal parts consist of the inductance L having the resistance R, a condenser K, battery E, interrupter U, an auxiliary resistance R_b for varying the initial current, and a micrometer spark gap S in parallel with the inductance and capacity. Let the current $i_0 = E/(R + R_b)$ be established, then provided the circuit at U is broken with sufficient suddenness to prevent a spark forming there, we shall have oscillations of potential at the electrodes of the micrometer spark gap, which, in view of the small values of K and R and the large values of L (see measurements below) may be accurately expressed by

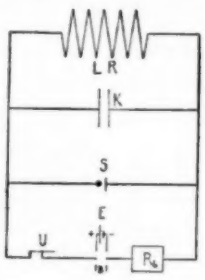

Fig. 1.

$$V = i_0\sqrt{\frac{L}{K}}\, e^{-\frac{R}{2L}t} \sin\left(\frac{t}{\sqrt{KL}}\right)$$

and which have the period $T = 2\pi\sqrt{KL}$.[1]

The method of observation consists in slowly lessening the width of the spark gap while interruptions of the current are being made until a spark takes place. The mean of several spark lengths so found is taken as the spark length corresponding to the initial current in the expression for V given above. The spark observations are made visually.

The condenser and inductance have been very fully described in previous communications from this laboratory and will be only briefly noticed here.

[1] Phys. Rev., 22, p. 131, 1906.

The *condenser*[1] consists of two thick steel plates of 25 cm. radius held apart by sets of three small cylinders cut from plane parallel plates of glass. The capacities were calculated from the formula of Kirchhoff. The range used in these experiments was between 200 and 600 cm.

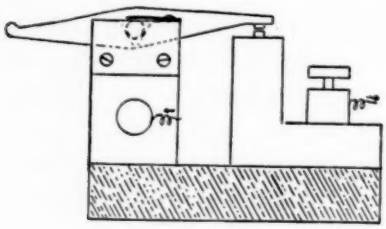

Fig. 2.

The *inductance*[2] consists of a coil of 3,600 turns of no. 18 (B. & S.) double cotton-covered copper wire wound in a large wooden spool. The channel filled with windings has a square cross-section 3 inches on a side, and its internal diameter is 8 in. The coil is divided into six independent sections of ten layers each; with all in series the inductance is 3.01 henries and the resistance 62 ohms. By using various combinations of sections a great range of inductance is possible.

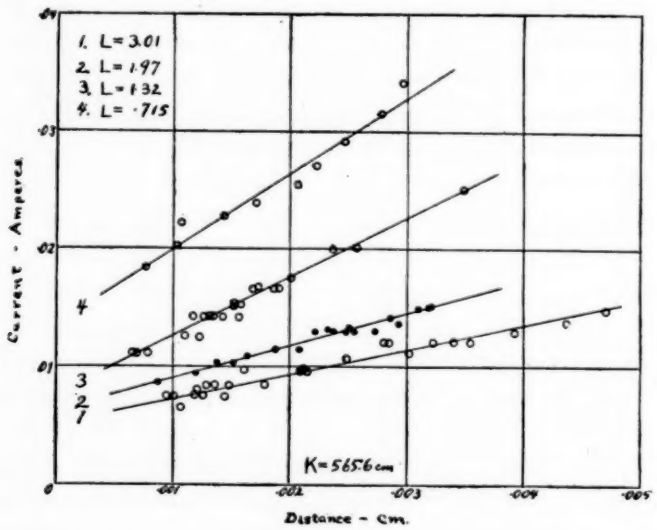

Fig. 3.

Besides this coil there were used two large coils from the Worcester Polytechnic Institute kindly loaned by Professor Duff. These had

[1] A. G. Webster, PHYS. REV., 6, p. 300, 1898.

[2] J. E. Ives, PHYS. REV., 14, p. 298, 1902.

an inductance when used in series of nearly a henry. It was found, however, that the insulation of these coils was not sufficient for work with any but the smallest sparks.

The *interrupter*, one of several designed by Professor Webster for use with the drop chronograph (*loc. cit.*), may be readily understood by a glance at Fig. 2. The circuit is broken by the falling of a weight on the end of a lever. The requirements are perfect rigidity and freedom from vibration when the lever arm is struck,

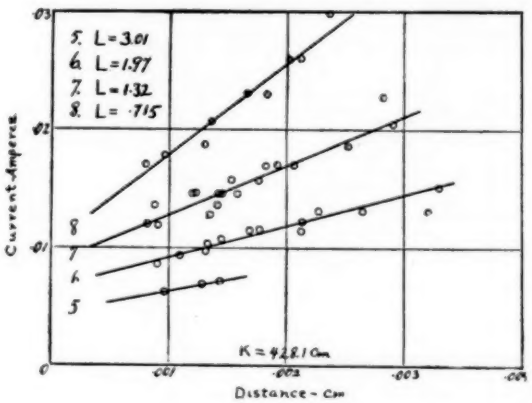

Fig. 4.

and a return to negligible resistance of contacts as soon as the circuit is closed. The lever should be of as small moment of inertia as is consistent with these requirements. The lever is of steel, shrunk on a steel axis which turns in V-shaped grooves in the tops of two upright projections of a brass frame. The latter is mounted on a block of ebonite which also carries the mounting for the other contact. A pair of stiff steel springs pressing the upper side of the axis keep it firmly in the grooves, and a stiff band of steel pressing against one end of the axis holds the other end against a metal stop mounted on the outside of the opposite post. Perfect and permanent adjustment is thus secured, the arrangement constituting a Kelvin so-called geometrical slide. The contacts are of silver and rubber bands (not shown) cause the contacts to press together as soon as the weight which operates the lever has done its work. This arrangement has given perfect satisfaction and stands the

roughest usage. The resistance of the interrupter with the circuit closed was invariably found to be a small fraction of an ohm.

The *circuit breaker* first tried was the projectile of the drop chronograph. Several seconds were required to produce a single interruption and many minutes to find a single spark length. In its place was substituted a bicycle wheel operated by an electric motor. The wheel carried a two pound mass of iron on its rim for striking the lever arm of the break, suitable counterpoise being added to the inside of the rim on the opposite side. The wheel was usually rotated so as to produce about two breaks per second.

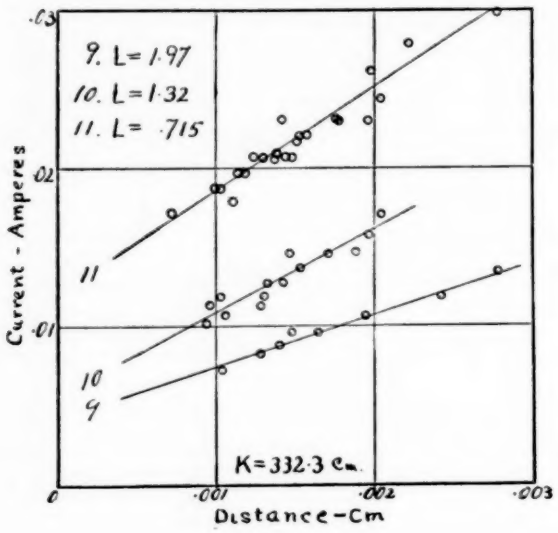

Fig. 5.

The *micrometer spark gap* is very similar in principle to many which have been described before.[1] The spark electrodes were of steel, one of them being a plane 10 × 12 mm., the other a ball 6.25 mm. in diameter mounted on the end of a brass cylinder of nearly the same diameter. These were ground with several pourings of flour of emery then given a high polish with diamantine on soft leather. The amount of labor involved in producing surfaces of high polish, free from scratches, on steel is extraordinary, and I am greatly indebted to Mr. H. F. Stimson, Scholar in Physics

[1] G. M. Hobbs, Phil. Mag. (6), 10, p. 620, December, 1905.

in Clark University, who undertook a careful study of the matter. Cleaning of the surfaces was effected by rubbing with soft, clean cloths, then with chamois skin and chalk or jeweller's rouge. Small particles of dust were removed by the use of an air jet. The plane was mounted in parallel ways and the ball with its axis of rotation at an acute angle with the plane. After the passage of a spark the plane was given a small translation and the ball a small rotaton so as to move the near surfaces in opposite directions, thus presenting fresh surfaces for the next spark. During the final measurements a jet of air (see below) was directed into the space between the electrodes. A separate circuit, the leads of which could be attached to the spark electrodes, containing a battery, resistance, and millivoltmeter was used to determine the position of contact of the electrodes. This zero was found immediately after the passage of each spark. It could be determined to one-tenth division of the drumhead of the micrometer screw, corresponding to .00002 cm. The results given here are mostly for sparks from .005 to .0005 cm. in length. The order of accuracy is therefore about one per cent. Difficulties of another sort discussed below render greater accuracy of reading useless for the present purpose.

Potentiometer and bridge circuits were arranged for frequently testing respectively the electromotive force E of the battery and the resistance of various parts of the system. For the battery E was used one or two storage cells.

Control Experiments.

Frequency of Interruption of the Circuit.—On changing from the drop chronograph to the bicycle-wheel break no change of result was observed, showing that it was immaterial whether the train of oscillations was applied to the spark gap once in many seconds or twice per second.

Surface of the Spark Electrodes.—Different methods of polishing and cleaning gave approximately the same results except for the higher frequencies where the passage of the spark is extremely sensitive to the state of the surfaces. Especial care had to be taken to use only the freshest of materials in cleaning the electrodes.

State of the Gas.—First experiments gave results which varied

by 50 per cent. among themselves. After much effort to get more uniform data it was found that a fine jet of air blown from a tapering glass tube into the discharge space reduced the necessary sparking potential to a very much lower value and enabled results to be repeated within a few per cent. of each other (curves 1–11, Figs.

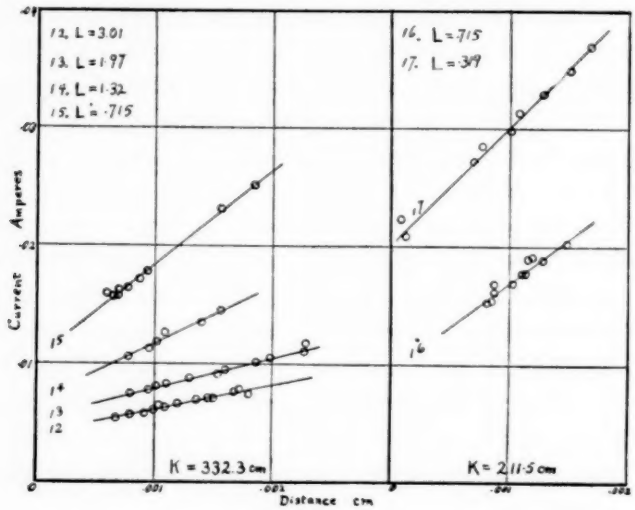

Fig. 6.

3–5).[1] Such discrepancies as then remained were found to be due to inefficient insulation in the windings of the coil, and before a last series of measurements was made were eliminated almost entirely by placing the coil in kerosene (curves 12–17, Fig. 6). Obviously, as the experiments go, there is no need to consider the effect of changes of atmospheric pressure. It may be remarked, however, that the most consistent results were obtained during rainy weather.

POTENTIAL AT THE TIME OF SPARKING.

While the damping in these experiments is small, it is of some

[1] The air coming from a filter-pump air-blast, the water in which was usually at about 6° C., passed through a long rubber tube and then through a plug of glass wool to filter out dust, before passing to the spark gap. The air was delivered at approximately the temperature of the room (20°) and was far from being saturated with moisture. The effect of the air was very striking, and seems to show that a part of the lag effect depends upon the number of ions initially present in the air. A tube containing a small quantity of radium placed under the spark gap produced similar results. A systematic study of the effect of various ionizing agents is to be made in later work.

interest to know whether the discharge begins during the first maximum of potential. It is conceivable that if the effect of a maximum were just unable to produce a spark it might succeed in forming ions which would enable the spark to pass at some following maximum. The first spark of condenser discharge has long

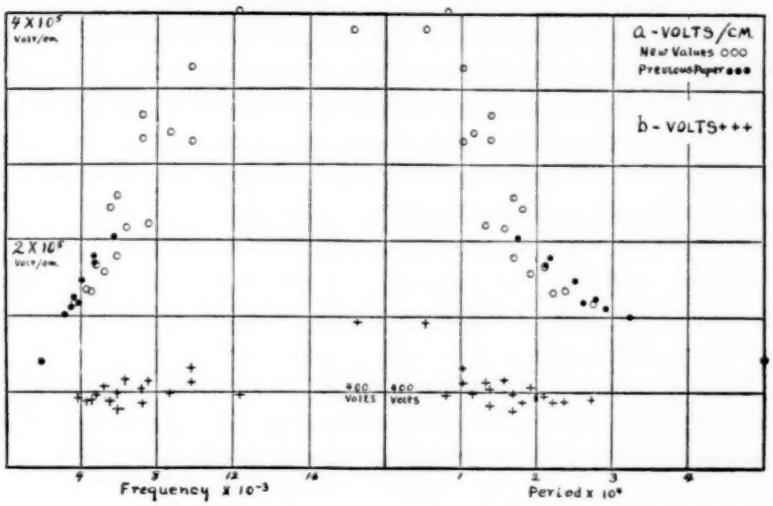

Fig. 7.

been known to be of different character from the others and has been given the name pilot spark. I have found evidence to show that, given a spark length and the oscillating potential which will just produce a spark, but not greater, the spark will begin during the first maximum of induced potential. A micrometer microscope was focused upon the space between the contacts of the break, and the velocity of break, at first high enough to prevent sparking altogether, was reduced until a very faint spark occurred. The length of the spark together with the known velocity of break and the frequency of oscillation placed the time of occurrence of the spark very near the time of the first maximum of potential, *i. e.*, within one eighth of the period. A small further reduction of the velocity of break caused a complete change in the character of the spark. It was now thick, brilliant and longer and possessed a beaded appearance. This is because the rapidly moving electrode was in

different positions at the times of successive oscillations. Measurement showed that the spark length for the first luminous condensation gave a time which invariably came in the second half period, again within one eighth period which was about the reading accuracy of the necessarily low power microscope. The pilot spark which must have preceded it was completely masked. In any event it would seem that the first spark takes place during the first maximum as was directly observed for the limiting case. For *constant* spark lengths at the micrometer spark gap no such changes were observed, which is easily understood as we do not there have the influence of the rapidly widening spark gap in preventing the second and successive discharges from passing. It seems probable, also, that unless the first maximum is great enough to produce a discharge, any ions that might be formed would be swept out of the field, making it less likely that the successive maxima would produce a discharge.

Further evidence on this question will be found in the discussion of results. Assuming that the spark takes place near the end of the first quarter period we have, in the most unfavorable case ($R = 27.1$ ohms, $L = .715$ henry, and $K = 6.28 \times 10^{-10}$ farads), as the value of the damping factor $e^{-\frac{R}{2L}\frac{\pi}{2}\sqrt{KL}} = .9987$, which is unity for our purpose. We therefore take

$$V = i_0 \sqrt{\frac{L}{K}} \sin\left(\frac{t}{\sqrt{KL}}\right)$$

and

$$V_m = i_0 \sqrt{\frac{L}{K}}. \qquad (1)$$

This discussion ignores the fact that the resistance of the coil for rapid oscillations increases somewhat rapidly with the frequency.[1] Since we have a margin of safety of several hundred per cent., it is hardly likely that the effect of the damping need be considered.

RESULTS.

Several series of observations were made to show the relationship between spark length and initial current. The results of these

[1] See, for example, A. Esau, Ann. der Phys. (4), 34, pp. 57 and 81, 1911.

measurements are shown graphically in Figs. 3–6. Abscissæ represent spark lengths in cm., and the ordinates represent the currents in amperes which were flowing at the various times of break and from which the potentials may be calculated from equation (1). Each point shown in the figures is a mean of several, usually five, readings.

The most important result of the measurements is at once seen from the figures; namely, that with given K and L and within the limits of the experiments the relation between initial current and spark length is a linear one. Lines best representing the results are drawn in the figures and are given numbers which correspond in general to the order in which the experiments were made. Series 1 and 2, however, contain observations weeks apart, some of the other series having been determined in the meantime. All the series obtained with the air jet in use are shown.

During most of the control experiments spark lengths were obtained up to .01 cm. Owing to the gradual deterioration of the insulation of the coils the available region of experiment became more restricted and by the time series 10 was reached it was almost impossible to get results at all, while such as were obtained scattered very badly. The coil was then immersed in kerosene for the remainder of the work, giving much more regular results (series 12–17). Immersion in kerosene did not, however, restore the available working region to its former value. Measurements taken with the two coils furnished by Professor Duff gave consistent readings for only the smallest initial currents which would produce visible sparks. These results indicate very clearly that for satisfactory work with these oscillations coils must be used of which there is no question as to high insulation. A coil is now being designed with which it is hoped to meet such objections in an extension of the work over a wider range of spark lengths and under varied conditions. It must be remarked, however, that no indication has been found of a change of slope of any of these curves due to the progressive deterioration of the insulation.

Treatment of the Observations.—Since the relationship between the initial current and the spark length is a linear one, and the slopes of the lines are affected by change in the inductance or

capacity only, it is at once evident that for oscillating potentials under such conditions the period alone and not the amplitude affects the spark constants. We may write

$$i_0 = \alpha x + \beta$$

as expressing the relation between the current i_0 and spark length x. The constants α and β depend only on K and L. Since

$$V_m = i_0\sqrt{L/K}$$

(see equation (1) and discussion above), we may write

$$V_m = \alpha\sqrt{L/K}\cdot x + \beta\sqrt{L/K} = ax + b \qquad (2)$$

where

$$a = \alpha\sqrt{L/K} = f_1(\sqrt{KL}), \text{ etc.}$$

It now remains to examine a and b as functions of the period. In Table I. are given the values of α and β from which the curves in Figs. 3–6 are drawn, together with the corresponding values of a and b, and the periods $T = 2\pi\sqrt{KL}$ and frequencies n. The values of a and b so found are plotted in Fig. 7 as functions both of frequency and of period. The figure at once suggests that, within the errors of experiment, the constant a is a linear function of the frequency. It must be remembered that a few observations more or less in Figs. 3–6 would change the slopes of the lines as well as the intercepts, and at higher frequencies especially the values of a and b are enormously sensitive to errors of original observations. The values of a obtained in my previous paper (*loc. cit.*, p. 154) by an indirect method are given in Table II. and are shown in the figure as filled circles. These agree in a striking manner with the results of the present measurements. This astonished me, inasmuch as the former work was done under entirely different conditions. In the first place, the air jet was not used, though the experiments were carried on in very damp spring weather. Again, in the former case the spark gap was widening at a rapid rate at the instant the spark took place, the rate being such that the electric force was practically uniform between the electrodes from the start. The agreement of the two sets of results raises questions which can only be settled by further experiments. It will be ex-

plained if the spark takes place at the time at which the potential gradient has reached its first maximum in both sets of experiments. This is further justification for our use of equation (1) in the present case and of the treatment of the results in the former.

TABLE I.[1]

No.	K, cm.	L, henries.	$T \times 10^4$	$n \times 10^{-3}$	a	β	$a \times 10^{-5}$ $\frac{\text{volts}}{\text{cm.}}$	δ, Volts.
1	565.6	3.01	2.73	3.66	2.10	.00523	1.45	362
2	565.6	1.97	2.21	4.52	2.77	628	1.55	352
3	565.6	1.32	1.81	5.52	4.98	764	2.28	350
4	565.6	.715	1.33	7.52	6.34	1360	2.14	458
5	428.1	3.01	2.37	4.22	1.97	440	1.57	350
6	428.1	1.97	1.92	5.21	2.66	662	1.72	426
7	428.1	1.32	1.58	6.35	4.05	878	2.11	462
8	428.1	.715	1.16	8.63	7.63	1026	2.96	397
9	332.3	1.97	1.69	5.90	3.27	415	2.38	303
10	332.3	1.32	1.39	7.21	5.19	565	3.10	338
11	332.3	.715	1.02	9.80	6.53	1202	2.87	529
12	332.3	3.01	2.10	4.76	1.96	422	1.77	382
13	332.3	1.97	1.69	5.90	2.54	540	1.86	394
14	332.3	1.32	1.39	7.21	4.84	696	2.89	416
15	332.3	.715	1.02	9.80	8.02	1024	3.53	451
16	211.5	.715	.814	12.29	7.28	964	4.01	384
17	211.5	.319	.545	18.35	10.46	2092	3.86	771

TABLE II.

From this journal, Vol. 22, p. 154, 1906.

$T \times 10^4$	$n \times 10^{-3}$	$a \times 10^{-5}$ $\frac{\text{volts}}{\text{cm.}}$
1.75	5.72	2.03
2.13	4.69	1.80
2.16	4.63	1.86
2.50	4.00	1.65
2.61	3.83	1.46
2.78	3.60	1.50
2.91	3.44	1.41
3.23	3.10	1.34
5.05	1.98	.93

[1] The resistances of the coils $L = 3.01$, 1.97, 1.32, .715, and .319 henries are, respectively, $R = 62.5$, 51.3, 38.8, 27.1, and 17.6 ohms. No other appreciable resistance takes part in the oscillations.

It is interesting to notice the trend of a assuming it to be a linear function of the frequency n. The results in Tables I. and II. give, by least squares, for

$$a = pn + c$$

the values p, = 21.49, and c = 81,800 volts/cm., the constant c is the value for n = 0, that is, the value of a for steady potentials. This value is not far from the values of a which have been determined by others with spark lengths of the same order for constant potentials; the results of Earhart,[1] for instance, giving a as about 65,000 volts/cm. A still better agreement will be shown if the observations for the higher frequencies, which are very sensitive to the condition of the electrode surfaces, are left out of account.

It cannot be said whether the constant b depends on the frequency. The values of b are very sensitive to errors in a. The results for b show a trend to larger values with increasing values of n, and indicate a value of about 350 volts for zero frequency, again in agreement with steady potential work. Values of b from the previous paper are not shown for the reason that their absolute values are too largely affected by the residual errors of the method of approximation used in their calculation.

It is unfortunate that means were not available for the measurement of the inductance and resistance of the coils at the various frequencies used. The inductance diminishes slowly, while the resistance rises more rapidly with the frequency.[2] Both these effects, if taken into account, would diminish the calculated values of a and b by several per cent., but not nearly by enough to account for the changes observed in a. For example, for the moderate frequency of 4,000 vib. per sec., our value of a is about three times that for zero frequency. Since a involves the square root of L, the latter, in order to account for the whole change, would have to be diminished by eight ninths or 89 per cent. by the effect of the frequency, an amount which is of entirely different order of magnitude from that indicated by such experiments and theory as are available. These considerations will, however, be taken into account in the new experiments which are being planned.

[1] Earhart, Phil. Mag., VI., 1, p. 147, 1901.

[2] Esau, *loc. cit.*; see also J. G. Coffin, Proc. Amer. Acad., 41, p. 789, 1906, etc.

Summary and Conclusions.

This paper presents a study of the relation between spark length, potential, and frequency for oscillating potentials having frequencies from 4,000 to 18,000 vib. per sec., and for spark lengths ranging from .005 to .0005 cm. The potentials are produced by interrupting a known initial current in a circuit containing inductance and capacity. The interruption is made in such a manner that no spark is produced at the break, thus giving definite values of potential at the electrodes of an auxiliary spark gap.

The effect of different amplitudes and frequencies of potential upon the spark constants a and b in the equation $V = ax + b$, usually employed to relate steady potentials V and spark lengths x, is studied. The experiments relate to air at atmospheric pressure.

1. Evidence is presented showing that the discharge produced by a train of oscillations begins near the time of the first maximum of the potential (control experiments, etc.).

2. It is found that the spark lengths are linearly related to the strengths of initial cu rent (Figs. 3–6), the inductance and capacity in the circuit remaining the same; *i. e.*, the spark constants in the equation $V = ax + b$ are independent of the amplitude alone of the oscillating potential.

3. The spark constants vary with the frequency. The constant a in the equation is, within the limits of the experiments, a rapidly increasing linear function of the frequency. When the frequency is zero, that is, for steady potentials, the value of a reduces to its normal value which for these short sparks is about 6.5×10^4 volts/cm. At a frequency of 4,000 vib./sec., for instance, the value of a is nearly three times normal. This statement means that for an oscillating potential of this frequency the maximum potential of an oscillation necessary to produce a spark must be about three times as great as the sparking value of the steady potential, and so on. The value of b is practically the same as for steady potentials, *i. e.*, about 350 volts, except that there is a slight tendency to increase with the frequency.

4. It may be concluded finally that the lag effect of the electric spark depends upon at least two independent factors: (1) Upon the amount of ionization initially present in the spark gap. This

factor is of an accidental nature and is subject to regulation and control (see control experiments). (2) The lag effect depends also upon some process which takes place in the gas and which takes time for its completion such that the shorter the time the greater is the necessary sparking potential. The latter factor will probably be found to depend upon the nature and condition of the gas (pressure, etc.).

These facts accord in a general way with the theory of the spark discharge as developed by Sir J. J. Thomson.

Apparatus for a further study of this phenomenon is under construction, it being evident (Fig. 6) that it will be possible to obtain results of considerable precision. With such results it may be possible by a study of different gases at different pressures to obtain much greater insight into the problem of ionization by an electric field.

CLARK UNIVERSITY,
January, 1911.

A LECTURE ELECTROSCOPE FOR RADIOACTIVITY AND OTHER IONIZATION EXPERIMENTS.

By John Zeleny.

IN the electroscope to be described, the usual method of measuring ionization currents by the rate of motion of gold leaves or of fibers is replaced by one where, instead, the period of pendular vibration of a leaf is measured, the leaf recharging itself automatically after it has lost a definite portion of its charge.

As the period may be made quite short for ionizations as small as that due to uranium, the method has some advantages and is especially adapted for lecture demonstrations. The automatic charging of the leaf makes the action continuous so that the electroscope requires no attention, and various effects may readily be compared in an impressive way by simply noting the changes in the period of the leaf's motion.

A convenient form of the instrument is represented in section in the accompanying figure. The cylindrical case M, with glass ends, is 6.2 cm. in diameter and 4.5 cm. wide, the attached bulb L containing calcium carbide for drying the air. The rectangular plate H is 4.5 cm. long and 8 mm. wide, and can be moved in and out by sliding the supporting rod through the ebonite plug shown. The front face of this plate is coated with india ink, and the plate is connected to a constant source of potential of about 100 volts.

The gold leaf G, about 6 cm. long and 5 mm. wide, is hung in front of the plate H from the rod which supports the horizontal disc D. An amber plug inside of an ebonite one insulates this system from the case.

The disc B forms a condenser with D, the air in which is to be subjected to the ionizing agency studied. The rod O, supporting B, permits of motion up and down, and is insulated from the case by the ebonite stem Q.

The electroscope is used in the following way. B is connected to

the case of the instrument which is earthed, and H is charged to a potential of about 100 volts. The gold leaf is attracted to the plate H and then repelled, the disc D becoming charged to the potential of H, nearly. The electrical field between B and D will cause an ionization current to flow when, for instance, the shallow tray C placed on top of D contains some radioactive material; and

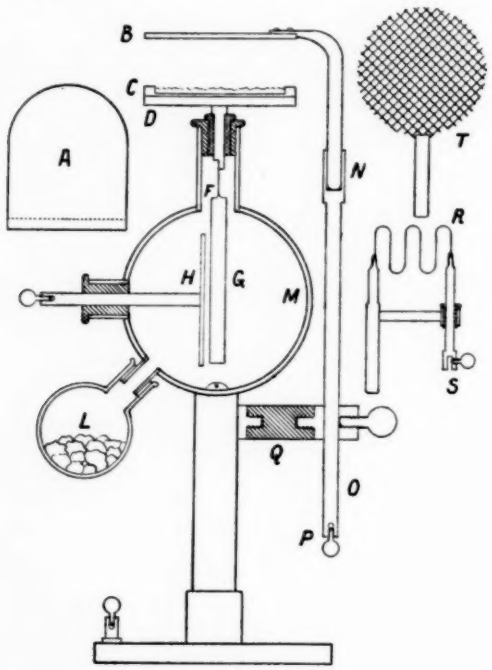

Fig. 1.

the gold leaf system will gradually lose its charge. After the leaf has lost a definite part, which need be but a small part, of its charge, it will be attracted over against H, again repelled and so on, the period of vibration of the leaf being a measure of the current flowing between B and D.

Absorption effects may be studied by placing sheets of material on top of the tray C.

The ionizing powers of γ rays and Röntgen rays may be shown by directing these rays at the electroscope from the side, while the conductivity of flame gases may be illustrated by blowing some of the air above a burner against the plates of the electroscope.

For showing the photo-electric effect, the disc *B* is removed, by pulling the rod out of the split sleeve *N*, and the wire gauze disc *T* is put in its place. Opposite this gauze there is placed on *D* the piece *A*, which consists of two similar metal plates joined at right angles, one being of zinc and the other of brass. By changing the position of the piece *A*, ultra-violet light may be projected through the gauze upon either a zinc or a brass surface. The effect of polarity is noted by reversing the charge on the plate *H*.

To illustrate the conduction produced by glowing bodies, the gauze *T* is replaced by the piece carrying the platinum wire *R*, which may be heated to incandescence by means of a current.

It will be noticed that the gold leaf *G* is placed with its plane at right angles to the plate *H*. To permit of motion in this plane, the leaf is cut part way across near the top at *F*, the upper portion being turned at right angles to the lower. When the plate and leaf are charged the electrical forces tend to keep the leaf in this edge on position. The chief advantage of this disposition is that the leaf, owing to the small resistance experienced when moving in its own plane, is repelled from the plate, after each contact, with an abrupt "kick," giving a sharp beginning and ending to each period. Any tendency of a leaf to adherence is also minimized by this arrangement.

Much difficulty was experienced at first, when the brass plate *H* was used with its natural surface, because the leaf would almost invariably stick to the plate. This adherence is doubtless due to a cohering effect caused by the rush of electricity across the contact-point when the leaf touches the plate. The smooth coating of india writing ink placed on the plate, besides making coherence more difficult, introduces considerable resistance at the point of contact and effectively overcomes the trouble.

The sensibility of the electroscope may be changed at will by altering the distance between the plate and leaf when these are charged. The potential to which the plate should be charged may vary from about 40 volts to 150 volts or more, the sensibility of the instrument not being greatly different between these limits provided the plate after being charged is pushed close up to the leaf. The potential for the greatest sensibility depends upon the

way each leaf hangs, and is that for which the leaf and plate are parallel when charged and close together. In general a potential of about 100 volts gives the best results, and a convenient way of obtaining this is from one of Kruger's boxes of minute cadmium cells.

The following data are given for illustration. Using uranium oxide in the tray C as the source of ionization, the distance between B and C being 2 cm. and H being at 100 volts, the period of the leaf was changed from 1.5 sec. to 40 sec. as the maximum distance between the leaf and plate was changed from less than 1 mm. to 8 mm. The loss of potential by the leaf between contacts with the plate was about 1.5 volts for each second of the period of the motion; so that for the shorter periods the strength of the electrical field between B and C was nearly constant throughout. The strength of this field may be varied, when desired, by disconnecting B from the case and charging it to any potential.

PHYSICAL LABORATORY,
UNIVERSITY OF MINNESOTA,
January 28, 1911.

SPARK DISCHARGE AT VERY SMALL DISTANCES.

By E. H. Williams.

IN a previous article[1] the author investigated the nature of spark discharge at very small distances, especially studying the effect of the material of which the electrodes are made upon the discharge potential. It was shown that not only does the material of which the electrodes are made have no effect upon the discharge potential, but that the nature of the discharge at very short distances is the same as for longer distances. It was also shown that the discharge potential for a distance between the electrodes of one wave-length of sodium light is the same as for five wave-lengths, and that for distances less than five wave-lengths the path of the discharge is not along the shortest distance. Results obtained in air of different degrees of dryness indicated that the nature of the dielectric affects the discharge potential in that this potential is lowered by the presence of moisture in the air between the electrodes. It is the purpose of this article to extend the above investigations, especially with reference to the effect of the dielectric and pressure upon the discharge potential.

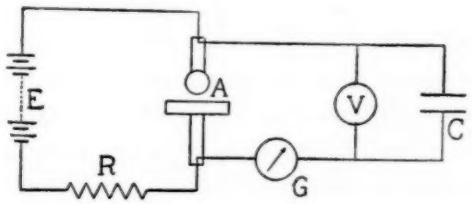

Fig. 1.

The apparatus and method of procedure were the same as in the work referred to above. The method of noting the passage of the spark, which was the same as in the previous work, was as follows. In Fig. 1, let E be a variable E.M.F., R a high resistance, two meg-

[1] E. H. Williams, Phys. Rev., 31, p. 216, 1910.

ohms or more, A the electrodes between which the spark passes, V an electrostatic voltmeter, C a small capacity in parallel with the voltmeter, and G a sensitive ballistic galvanometer. Now, when a discharge takes place between the electrodes at A, the potential between the electrodes is lowered for an instant and the condenser system is allowed to discharge through the ballistic galvanometer G, producing a deflection. It was noted, by watching the spark gap and galvanometer at the same time for a large number of readings, that the galvanometer invariably indicated the passage of a spark. It was also observed that the pointer of the voltmeter gave a slight deflection at the instant that the spark passed. The magnitude of the deflection of the galvanometer, or of the voltmeter, could be increased by increasing the resistance R. A telephone receiver, inserted in place of the galvanometer G, is an equally good indicator. By using the capacity C, the quantity of electricity passing through the galvanometer is greater and the time necessary for this quantity to be replaced is correspondingly increased.

NATURE OF THE GAS: EFFECT OF VARIOUS GASES.

In all of the previous work, air was used as the dielectric. It was now proposed to use hydrogen and carbon dioxide. After the box had been washed out with the gas, it was allowed to stand for some time in order that any moisture remaining in the gas might be taken up by the sulphuric acid in the box. The results, which are shown in Tables I. and II., confirm the former conclusion that the nature of the dielectric does affect the discharge potential. According to these results the minimum potential for hydrogen is about 248 volts, while that for carbon dioxide is about 425 volts. The minimum potential for air under the same conditions was previously found to be about 372 volts. In the above tables, which include two or three series taken on different days, distances in wave-lengths are given in the column under λ and potential differences in volts in the column under V.

Effect of Pressure.—The pressure of the gas surrounding the electrodes was varied from one atmosphere to one centimeter of mercury and the effects studied. The results are shown in Tables III., IV. and V. The general trend of these results indicates that

TABLE I.

Hydrogen. Platinum+ Brass−

λ	V	λ	V	λ	V
1.5	247	2.	243	3.	248
1.5	244	2.	249	3.	248
1.5	227	2.	247	3.	245
1.5	240	2.	248	3.	248
1.5	240	2.	247	3.	249
1.5	232	2.	247	5.	249
1.5	246	2.	240	5.	247
1.5	238	2.	249	5.	243
1.5	246	3.	249	5.	252
1.5	237	3.	248	5.	251
2.	246	3.	246	5.	248
2.	247	3.	241	5.	249
2.	247	3.	244	5.	250
2.	244	3.	248	5.	253
2.	241	3.	251	5.	248
2.	247	3.	249	5.	247

the minimum potential is not affected by pressure, although some of the readings point to the contrary, in that they are much higher than the minimum potential for air at atmospheric pressure. Now,

TABLE II.

Carbon Dioxide. Platinum+ Brass−

λ	V	λ	V	λ	V
2.	362	3.	427	5.	427
2.	410	3.	425	5.	427
2.	380	3.	422	5.	426
2.	422	3.	424	5.	425
2.	414	3.	421	5.	424
2.	423	3.	423	5.	423
2.	407	3.	423	5.	425
2.	423	3.	423	5.	426
2.	422	3.	425	5.	423
2.	425	3.	423	5.	427
3.	424	3.	423	5.	425
3.	427	3.	424	5.	424

if the conditions can be made such that few ions are present in the box which surrounds the apparatus, it is possible that there will

be no ions present between the electrodes. If such is the case, the potential may be raised above the minimum potential without producing a spark. Evidently the chances for such conditions are augmented as the pressure decreases. As soon as an ion is drawn into the field between the electrodes a spark will pass. It is to be expected that there will be no regularity in the discharge potential when these exceed the minimum potential.

TABLE III.

Pressure = 30 *cm. of Hg. Platinum* + *Brass* −

λ	V	λ	V	λ	V
1.5	376	2.	372	3.	372
1.5	372	2.	369	3.	372
1.5	372	2.	373	3.	415
1.5	380	2.	372	3.	373
1.5	362	2.	370	5.	369
1.5	372	2.	371	5.	420
1.5	371	2.	371	5.	372
1.5	372	3.	372	5.	373
2.	368	3.	368	5.	369
2.	372	3.	370	5.	372
2.	370	3.	371	5.	372
2.	369	3.	373	5.	373

TABLE IV.

Pressure = 10 *cm. of Hg. Platinum* + *Brass* −

λ	V	λ	V	λ	V
1.5	393	2.	425	3.	398
1.5	370	2.	372	5.	372
1.5	311	2.	369	5.	372
1.5	373	2.	375	5.	435
1.5	372	2.	372	5.	371
1.5	373	3.	370	5.	372
1.5	328	3.	371	5.	380
1.5	371	3.	374	5.	382
2.	370	3.	372	5.	373
2.	371	3.	445	5.	372
2.	368	3.	372	5.	372
2.	412	3.	372	5.	371
2.	372	3.	373	5.	385

TABLE V.

Pressure = 1 *cm. of Hg. Platinum* + *Brass* −

λ	V	λ	V	λ	V
1.5	329	2.	372	3.	370
1.5	370	2.	372	3.	394
1.5	369	2.	370	3.	370
1.5	342	2.	373	3.	371
1.5	371	2.	371	5.	445
2.	372	3.	445	5.	370
2.	378	3.	373	5.	405
2.	370	3.	370	5.	390
2.	413	3.	374	5.	443
2.	373	3.	372	5.	372
2.	409	3.	465	5.	406
2.	372	3.	445	5.	370
2.	463	3.	372	5.	373

Effect of Ultra-violet Light and Electric Waves upon the Discharge Potential.—In the article referred to above, the effect of ultra-violet light was found to be very large. However, the results for 1.5λ, 2λ and 3λ were very irregular, and since the ultra-violet light was produced by an electric spark between two aluminum electrodes inclosed in a quartz tube, it seemed possible that the large effect might not all be due to the ultra-violet light but that some of it might be due to electric waves or to other external effects due to the presence of high potentials in the neighborhood of the electrodes. In order to decide this point an electric arc between electrodes of iron and of mercury inclosed in a quartz tube was used as the source of ultra-violet light. This arrangement possessed the advantage that only low external potentials were applied in the neighborhood of the electrodes (14 volts across the arc), and that no electric waves were present. Therefore, any effect that might be produced would be entirely due to ultra-violet light. After a large number of observations, the conclusion was reached that the effect of ultra-violet light is very small, and that the large effect in the previous results is due to other causes.

That electric waves have an effect upon the discharge potential is evident from the difference in the results obtained with the two

sources of ultra-violet light—spark discharge and the electric arc. It is also apparent that the magnitude of the effect of the electric waves will depend upon the tuning of the system containing the electrodes to the particular wave-lengths used.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS,
February, 1911.

A CHARACTERISTIC OF SPECTRAL ENERGY CURVES. —A CORRECTION.

By W. W. Coblentz.

UNDER the above title[1] the writer gave the complete solution of Planck's spectral energy equation in order to obtain the wave-length of the maximum of emission, "λ_{max}" which is useful in determining the constants entering into this equation.

The object of the present communication is to call attention to several errors in the published solution for "λ_{max}." The value of "α" as it was used in the computations is $\alpha = 4.9651$, and in order to avoid confusion with $\alpha = 5$ (Wien equation) should have been written α'. The first terms should contain the factor α/α'. The complete solution is

$$\lambda_{max} = \frac{\alpha(\log \lambda_2 - \log \lambda_1)\lambda_1\lambda_2}{\alpha'(\lambda_2 - \lambda_1)\log e} + \frac{\lambda_1\lambda_2\left[\log\left(1 - e^{-\frac{\alpha'\lambda_m}{\lambda_2}}\right) - \log\left(1 - e^{-\frac{\alpha'\lambda_m}{\lambda_1}}\right)\right]}{\alpha'(\lambda_2 - \lambda_1)\log e}. \tag{1}$$

This follows directly by equating the Planck equation for $E_{\lambda_1} = E_{\lambda_2}$, writing $c_2 = \alpha'\lambda_m T$, taking logarithms, and solving for λ_{max}.

The more cumbersome (second) term previously published was obtained from this equation. In the computations the second term, which enters as a correction factor, is not so complicated as it may seem, for usually when λ_1 is small, this term may be neglected. Furthermore the correction factor need be computed for only three to five points on the long wave-length side of the spectral energy curve, through which a curve is drawn. From this curve the correction factors for other values of λ_2 may be read with a greater precision than demanded by the experiments.[2]

[1] Phys. Rev., 29, p. 553, 1909.

[2] See Table I., Jahrb. Radioaktivität und Elektronik, 8, p. 1, 1911.

By expanding[1] log $(1-e^{-k})$ and neglecting higher powers of e^{-k} equation (1) reduces to

$$(2) \qquad \lambda_{max} = \frac{\alpha(\log \lambda_2 - \log \lambda_1)\lambda_1\lambda_2}{\alpha'(\lambda_2 - \lambda_1)\log e} + \frac{\lambda_1\lambda_2[e^{-\frac{\alpha'\lambda_m}{\lambda_1}} - e^{-\frac{\alpha'\lambda_m}{\lambda_2}}]}{\alpha'(\lambda_2 - \lambda_1)\log e}.$$

This is sufficiently accurate[1] for the experimental data now available, but with each renewed effort a higher accuracy in the observational work is attained, which requires greater refinement in the computations. For example the equations kindly given me by Dr. Buckingham and used in the data published a year ago,[2] were applicable over only a narrow spectral region and hence too arbitrary. However, by computing a series of correction curves for the region of 3 to 5μ and extrapolating in both directions, it was possible to obtain fairly accurate data as shown[2] in Table I. of the aforesaid paper.

During the past three years more than 80 spectral energy curves have been obtained, under all sorts of conditions. It is hoped that the complete discussion of the instruments and methods used in obtaining these data and of the aforesaid equations employed in the computations, also the applications of the results may be given in the near future. It will be sufficient to add that the Planck equation appears to be valid for the temperature range from 450° to 1530° C. and for the spectral region to 6.5μ, provided the radiating enclosure is "black."

[1] Mr. Dellinger has found that but small errors are introduced by dropping all factors in this expansion except $e^{-\frac{\alpha'\lambda_m}{\lambda_2}}$ which further simplifies the second term of eq. (2). In actual practice, however, the writer prefers to retain the factor $e^{-\frac{\alpha'\lambda_m}{\lambda_1}}$ as given in equation 2, but using it only when λ_1 and λ_2 are close together, *i. e.*, near the maximum of the spectral energy curve where the correction due to this term may amount to .6 per cent.

[2] PHYS. REV., 31, p. 317, 1910.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE FIFTY-SEVENTH MEETING.

THE regular spring meeting of the Physical Society was held in Washington, D. C., on Friday, April 21, and Saturday, April 22, 1911, the Friday session being held in the lecture room of the Cosmos Club and the Saturday sessions at the Bureau of Standards. President Magie presided at the Friday session and Vice-President Peirce on Saturday.

A portion of the Friday session was devoted to a discussion of the relations between the Society and the Physical Review, and to the general question of the publication of the results of investigations by American physicists. In introducing the discussion the president presented to the meeting, on behalf of the council, the following communication from the editors of the Physical Review:

To the Members of Council of the American Physical Society:

The conference held in New York on March 3, for the purpose of discussing the relations between the Physical Society and the Physical Review and the question of the establishment by the society of one or more new journals, was unfortunately attended by only four members, and there was thus no opportunity for a really adequate discussion of the matter. Since the members of the council are so widely separated, it seems unlikely that a well attended conference can be had in the immediate future. It has seemed to us, therefore, that the discussion of the whole question would be facilitated by a statement to the council of the attitude of the editors of the Rexiew toward the different propositions that have been advanced.

In connection with the recent mail ballot on the question of the relations between the society and *Science Abstracts* and the *Physical Review*, the secretary has received numerous comments and suggestions and a number of long letters dealing with the matter. Aside from the discussion of methods of economy in conducting the Review, the sug-

gestions fall under two heads: (*a*) that the board of editors be enlarged so as to be more representative of the whole country, thus removing the objection that exists in the minds of many to the present local character of the board; (*b*) that the Physical Society assume full responsibility for the Review. A recent proposition of Professor Ames for the society to establish two new journals adds another to the plans suggested. In what follows, we take up each plan in turn and give a brief statement of the position of the editors of the Review in reference to it.

1. The proposition of Professor Ames that the society establish one or more new journals.

The establishment of another new journal of the same scope as the Physical Review seems inadvisable. If, however, there is a desire to establish a journal radically different from the Review in character or policy, the editors of the Review can see no objection. Whether or not members of the society would continue to receive the Review at a reduced price could be decided later.

2. The proposition that the Physical Society assume control of the Physical Review.

The chief factors in determining the attitude of the editors of the Review toward such a proposition are first the sentiment of the members of the Physical Society, and second the question of the practicability of the society's carrying out the plan at the present time. Whatever degree of success has been attained by the Review represents a considerable investment both of money and effort, and this fact places upon the editors a certain responsibility for the future which they cannot lightly avoid.

It has been the policy of the Review to offer a channel for the publication of all reputable research work in physics carried on in the United States and Canada. Articles are accepted from members of the Physical Society, and from physicists not belonging to the society, on the same terms. The publication of an article in the Review is not an indication that the editors regard the article as of preëminent excellence or that they agree with its conclusions; it simply means that, in the opinion of the editors, the article contains enough of value to make it deserve a hearing. Briefly put, the policy of the Review has been democracy in science as opposed to aristocracy.

It would be an essential condition for the transfer of the Review to the society that in regard to these points, and in all other important respects, the policy of the Review should remain the same as in the past, until it is shown by a vote of the society that a change is desired by at least two-thirds of the regular members. We should further stipulate that the name Physical Review be retained.

In the event of the society's assuming control of the Review we

should expect it also to assume full financial responsibility. This would of course mean that the cost of the Review to the society would be considerably greater than under either of the plans proposed in the recent mail ballot. We should not feel justified in turning over the control and responsibility until it has been demonstrated that a majority of the members are willing to assume this added burden.

We should regard it as essential that the first board of editors be so constituted as to make reasonably certain that its members are in sympathy with the policy of the Review and will work in harmony with the present editors during the period of transition. We should suggest therefore that the selection of the editorial board and of the active editors be made in such manner as will insure the approval both of the society and of the present editors.

If the transfer should be made there will doubtless be other matters of minor importance where it will be necessary for the society and the present editors of the Review to reach an agreement. We should not anticipate any difficulty in the arrangement of such details.

If a change should be made with the cordial support of the members of the society we feel that the success of the undertaking is reasonably certain. But to provide for the possibility of a different result, the editors make the final stipulation that if difficulty should be experienced in properly maintaining the Review, the society shall not accept financial aid, under circumstances which place the society under obligations to any individual or institution, until the present editors have been offered the option of resuming the control and financial responsibility which they now have.

3. The proposition, which has come in a variety of forms, that a representative board of editors be selected to coöperate with the present editors by giving their assistance and advice.

If this plan should meet with approval it is our intention to suggest as the members of the first board the eight elected members of the council, namely, Messrs. Guthe, McLennan, Millikan, E. F. Nichols, Sabine, Skinner, Stratton, and Zeleny. The exact functions of this board, and any changes which might be made in the method of conducting the Review, could be decided upon after consultation between the board and the editors of the Review. Our desire would be to have the connection between this board and the editorial control of the Review an active one and not merely nominal. We should suggest that the members of this board retire two each year and that their successors be elected by the society. We think, however, that the council should not constitute the board *ex-officio*. (This is the plan which the editors had decided upon several months ago, and which they had intended to suggest as soon as the question of the financial relations between the society and the

Review had been settled. If the council should feel any hesitation in regard to the proposed selection of the eight elected members of that body as members of the first board, it would doubtless be possible to find a different board which would be mutually satisfactory. The editors feel, however, that the proposed board,—owing to its representative character, geographically and otherwise,—is likely to be more satisfactory to the society, as well as to the editors of the Review, than any other that we have considered.)

The difference between plans 2 and 3 is largely, although of course not wholly, a difference in the location of financial responsibility. Under plan 2 full financial responsibility would be assumed by the society, in which case the discontinuance of *Science Abstracts*, or an increase of the dues to $8.50, seems to us unavoidable. Under plan 3 the Review would be compelled for a time to receive partial financial support from some other source than the society. This plan, in our opinion, is to be regarded as one step toward the ultimate assumption by the society of the complete responsibility called for in plan 2. While we should welcome the immediate relief from financial responsibility and editorial routine which would result from the adoption of plan 2, we feel that in some ways it would be safer for the society to proceed more slowly.

Of the three plans proposed, we feel that the first and second are mutually exclusive. If the society assumes responsibility for the Review, it would be inadvisable, from the financial point of view, for it to attempt at present to support another journal.

Plans 1 and 3, however, we regard as entirely independent, so that both may be adopted if the society so desires. The establishment of an enlarged editorial board for the Review would be fully as desirable if the Review is conducted without any financial connection with the society as under any other conditions.

When the council has reached a conclusion the next step, in our opinion, is to submit the whole matter to a vote of the society. In connection with this vote we should consider it essential that a statement of the whole situation be sent to each member, so that he may vote with a clear understanding of the responsibilities, financial and otherwise, which the society proposes to assume.

We shall be glad to place at the disposal of the council any information in regard to the Physical Review which they may need in discussing the situation. And we desire in conclusion to express our willingness to coöperate in whatever plan seems to the society to be best calculated to advance the interests of physics.

(Signed) EDW. L. NICHOLS,
ERNEST MERRITT,
FREDERICK BEDELL.

March, 1911.

The discussion of the general question and the consideration of the above communication were carried on in committee of the whole, Mr. E. B. Rosa being elected chairman. Messrs. Webster, Magie, Arthur W. Smith, Humphreys, Merritt, Northrup, Hyde, Peirce, Carhart, W. P. White and D. C. Miller took part in the discussion. When the committee rose the chairman announced the adoption of the following two resolutions:

1. *Resolved*, that this meeting requests the council to present to the society a plan by which the society shall publish a journal.

2. *Resolved*, further, that the council be requested to enter into negotiations with the editors of the Physical Review to determine under what conditions the control of the Review may be transferred to the society.

The following papers were presented:

The Capacity of Phase Difference of Paraffin Paper Condensers as Functions of Temperature and Frequency. F. W. GROVER.

Resistance Coils for Alternating Current Work. H. L. CURTIS and F. W. GROVER.

A New Determination of the Selective Radiation from Tantalum. EDWARD P. HYDE.

Spectroscopic Evidence of Molecular Clustering. W. W. STRONG.

The Use of the Silicon Detector with Short Electric Waves and the Theory of Contact Detectors. ERNEST MERRITT.

The Theory of Dispersion and the Residual Rays. (By title.) O. W. RICHARDSON.

Note on Paschen's Method of Equal Ordinates for finding λ_m and C_2. (By title.) EDGAR BUCKINGHAM.

Recent Determinations of the Elementary Electrical Charge. WM. W. COBLENTZ.

The Detection of Small Heat Effects at High Temperatures. W. P. WHITE.

The Radiant Efficiency of Arc Lamps. H. P. GAGE.

The Physical Implication of the Principle of Relativity and the Definition of Mass. D. F. COMSTOCK.

Positive Thermions from Salts of Alkali Earths. C. J. DAVISON.

Photographs of Sound Waves from Various Sources. D. C. MILLER.

The Determination of the Form of Sound Waves by Means of a New Manometric Flame. J. G. BROWN.

The Elastic Properties of a Series of Iron-Carbon Alloys. (By title.) C. W. WAGGONER.

The Saturation Value of the Specific Intensity of Magnetization of Cobalt at Various Temperatures. (By title.) W. W. STIFLER.

Heat of Evaporation of Water at 100° C. ARTHUR W. SMITH.

Photoelectric Properties of Thin Cathode Films. P. H. DIKE.

The Difference in the Photoelectric Effect caused by Incident and Emergent Light. OTTO STUHLMANN, JR.

The Thermodynamics of Concentration Cells. H. S. CARHART.

On the Positive Potential of Alkali Metals as a Function of the Frequency of Ultra-violet Light, and the Determination of the Wave-length Equivalent of Roentgen Rays. (By title.) J. KUNZ.

The Enclosed Arc for Spectroscopic Work. JAMES BARNES.

On the Fusion of Carbon. O. P. WATTS and C. E. MENDENHALL.

Photographs of Vortex Rings in Liquids. E. F. NORTHRUP.

A Method for Eliminating the Effect of all Connecting Resistances in the Thomson Bridge. F. WENNER.

The Construction of Primary Mercurial Resistance Standards. F. A. WOLFF, M. P. SHOEMAKER, and C. A. BRIGGS.

A Tubular Electrodynamometer for Very Heavy Currents. P. G. AGNEW.

The Deflection Potentiometer Considered as a Generalized Null Instrument. H. B. BROOKS.

On Different Types of Potentiometer suitable for Thermo-electric and other Exacting Work. W. P. WHITE.

The Bureau of Standards' Current Balances. E. B. ROSA, N. E. DORSEY, and J. M. MILLER.

The Spectra of Aluminum, Copper, and Magnesium in the Arc under Reduced Pressure. JAMES BARNES.

A Heterochromatic Photometer. H. P. GAGE.

Ultra-violet Light from the Arc. H. P. GAGE.

The Measurement of Inductances with very small Time Constant. F. W. GROVER and H. L. CURTIS.

The Rôle Played by Gases in the Emission of Positive Thermions from Salts. C. J. DAVISON.

Methods of Increasing Calorimetric Accuracy. (By title.) W. P. WHITE.

At the close of the meeting it was voted to express the thanks of the Society to the Cosmos Club and to the scientific staff of the Bureau of Standards for the hospitality extended to the members of the society.

ERNEST MERRITT,
Secretary.

The Bureau of Standards' Current Balances.[1]

By E. B. Rosa, N. E. Dorsey and J. M. Miller.

THE current balances of the Bureau of Standards are of the type used by Lord Rayleigh, each consisting of a pair of fixed coils of equal radii and of square cross-section, and fixed at such a distance apart that the force upon the moving coil, also of square cross-section but of a smaller radius, suspended midway between the fixed coils and coaxial with them, is a maximum.

The balances were constructed in the shops of the bureau. The most novel features in their construction are the provision for water-cooling the fixed coils, the surrounding of the moving coil by a double-walled jacket maintained at a constant temperature by water circulation, and the making of the coils interchangeable so that many combinations of coils may be obtained.

All coils are wound bifilar of enamel insulated wire upon brass forms. To improve the winding, a layer of thin paper is placed over each layer before the next is wound. Over the outer layer of wire is placed a layer of paraffined paper, and two layers of cloth soaked in hot paraffin and well ironed on, with a hot block of brass, so as to effectually seal the coil from changes in atmospheric humidity. For further precaution, a layer of soft wax is melted on over the paraffin seal.

One moving coil (no. 4) had paraffin painted between the wires, and a strip of paraffined paper ironed down upon each layer as wound; it thus has its windings embedded in a practically solid block of paraffin.

Three pairs of fixed coils have been constructed, viz., one 40 cm. in diameter, each winding of 392 turns, forms of cast brass; one 50 cm. in diameter, each winding of 648 turns, forms of cast brass; one 50 cm. in diameter, each winding of 647 turns, forms built up of half-hard rolled brass.

Four moving coils have been constructed, viz., one 20 cm. in diameter, each winding of 72 turns, form of cast brass not sufficiently non-magnetic and consequently discarded; one 25 cm. in diameter, each winding of 72 turns, form of cast brass; one 20 cm. in diameter, each winding of 98 turns, form of cast brass; one 25 cm. in diameter, each winding of 71 turns, form cast from best rolled brass.

All portions of the balance have been tested by a very sensitive astatic magnetometer, and, excepting the discarded moving coil, found to be sufficiently non-magnetic.

All weighings having been made with the coils in the positions for maximum force, the only direct measurements of length needed are those

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

of the sectional dimensions of the coils, the main term in the expression for the force being completely determined by the *ratio* of the radii of the coils. This ratio was determined by a method identical in principle with that given by Bosscha, and used by Lord Rayleigh. The coils to be compared were placed concentric, coplanar, with their planes vertical and in the magnetic meridian. Currents were then passed in opposite directions through the two coils and adjusted until the resultant field, as indicated by a small magnetometer needle in the center of the coils, was zero; the two currents were at this instant simultaneously measured by two potentiometers. The ratio of these currents, corrected for the length of the magnetometer needle, is equal to the inverse ratio of the "galvanometer constants" of the two coils, and it gives at once the ratio of the two mean radii when the numbers of turns and the sectional dimensions of the coils are known.

With care it is not difficult to obtain the ratio of the galvanometer constants of two such coils with an accuracy of about 2 in a million. A careful study was made of the temperature coefficients of the coils and of the variations in the galvanometer constants with the load.

In assembling the balance proper, the correct position of the moving coil was determined electrically, and experimental methods were devised for determining the lack of coaxiality and the error in the spacing of the fixed coils, and for determining the effect, if any, of any fixed magnetic bodies that might be near the balance.

About two years and a half have been spent in strictly preliminary work, in the development of details of construction and of manipulation, and in the study of the various sources of error. The final result is based upon the observations of the next succeeding six months, and does not differ from the earlier observations by more than a few parts in 100,000.

The final weighings show that the electromotive force of the Weston normal reference cells of the Bureau of Standards is 1.01823 volts, in terms of the international ohm.

That is, the Weston cells have an electromotive force of 1.01823 absolute volts if the international ohm is equal to the absolute ohm. The value of the E.M.F. of these coils is 1.01830 international volts (in terms of the international ohm and the silver voltameter), showing an apparent difference between the absolute volt and the international volt of 0.00007 volt. However, there is perhaps a greater difference than this between the absolute ohm and the international ohm; hence we cannot say definitely until the absolute ohm is better determined whether the international volt or the absolute volt is the larger.

The following values have been found by other observers during the last four years:

1907	National Physical Laboratory	1.01818
1908	Laboratoire central d'Électricité	1.01870
	Laboratoire central d'Électricité	1.01841
	Guillet	1.01819
	Guillet	1.01825
1910	Haga	1.01825
1911	Bureau of Standards	1.01823

These results seem to indicate that the electromotive force of the Weston normal cell at 20°.00 C. in terms of the international ohm and the absolute ampere is 1.01822 volts to within a few parts in 100,000.

A Method for Increasing Calorimetric Accuracy.[1]

By Walter P. White.

In a series of articles on calorimetry, published in the previous volume of this Review, I tried to show that the cooling of calorimeters can easily be made to occur under conditions so definite and measurable that all errors due to irregularity or uncertainty of the cooling are quite imperceptible. There is, however, a source of error due indirectly to the cooling, namely, an increase in the number of accurate thermometric measurements, and therefore in the accidental thermometric error, due to the necessity of determining the cooling rate from which to calculate the correction. It was pointed out that this increase of accidental thermometric error could be avoided by keeping the cooling factor constant—repeated measurements of the cooling rate would then be unnecessary—and further that with such a procedure the error could again be decreased by choosing the initial temperatures so that the total correction was small; the absolute effect of a given proportional error in the value of the rate would thereby be diminished.

To decrease the total correction by suitable choice of initial temperature of course diminishes the accidental error in those cases, also, where the cooling rate is observed. This rather evident conclusion seems to deserve mention here for two reasons:

(1) It was, unfortunately, not clearly stated in the articles referred to; and (2) I have recently found, contrary to expectation, that it is not true to the same extent where the Pfaundler formula is used. More explicitly, the facts are these: If we use as a standard of comparison the accidental thermometric error obtained when the calorimeter is initially at the jacket temperature, then, if a single cooling period only is used, the reduction of the correction by choice of initial temperature reduces the maximum possible accidental thermometric error of a single determination by one

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

half, and the mean probable error of a series by about one third; with the Pfaundler method, and two cooling periods, the maximum error is not reduced at all, and the mean error only by one sixth, and this value occurs not when the correction is a minimum, but when the jacket temperature is half way between the initial and final temperatures of the calorimeter.

Since the accidental thermometric error is the principal error in ordinary calorimetry, the maximum accuracy will generally be found in those methods which most diminish it. From this fact and those stated above it follows that: (1) Maximum accuracy will be obtained only through a reduced cooling correction along with a cooling factor either constant or determined from a *single* cooling period; along with a reduced correction, or else through a constant factor, either with or without a reduced correction; in either case with some method calling for a measured jacket temperature and a knowledge of the heat of stirring and evaporation. (2) The Pfaundler formula is incompatible with maximum accuracy, though it may give something more than half the maximum. (3) The procedure often recommended, of reducing the total cooling correction by choice of initial temperature, is practically useless with the Pfaundler formula. (4) Study of cooling correction errors and formulæ has thus far failed to explain the experimental result reported by some observers, that such reduction did diminish the accidental error.

Of course an increase in the length of the cooling periods diminishes the proportional effect of accidental temperature errors, and thus resembles a reduction in the correction. It is, however, time wasting and likely to introduce other errors. It is, therefore, of little practical importance.

Of course, the greater error with the Pfaundler formula method is not serious, and will often be outweighed by other advantages to be derived from employing that method.

THE CONSTRUCTION OF PRIMARY MERCURIAL RESISTANCE STANDARDS.[1]

BY F. A. WOLFF, M. P. SHOEMAKER AND C. A. BRIGGS.

THE paper deals with the construction of four one-ohm mercury standards in accordance with the specifications adopted by the London International Electrical Conference.

The tubes are of Jena 59^{III} glass and were calibrated over a length of 110 centimeters, the caliber factors of none of the tubes exceeding 1.0001. The tubes were cut at points giving a resistance for the finished tubes, including the end correction, of approximately one ohm. The ends were ground and optically polished to a plane (within one half

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

wave-length) very approximately at right angles to the axis. In addition, the tubes were tapered at the ends and ground to fit the end bulbs for electrical measurements and the glass cleaning and drying fittings.

The tubes were cleaned by dilute nitric acid, water, fuming sulphuric acid and water after which they were dried by drawing through them air which had passed through calcium chloride bulbs and by evacuation preliminary to filling.

The Reichsanstalt method was employed for determining the mass of mercury contained in the tube between the terminal planes. The lower end of the tube was closed by a plane glass plate clamped to the tube by means of a steel screw with an intermediate ball and socket joint, the screw being threaded through a yoke screwed to a steel collar cemented to the tube. After exhausting by means of a Geryk pump and with the end of the tube under mercury, mercury was admitted by rotating the receptacle containing it which was provided with a steel plate with a hexagonal hole to engage the hexagonal head of the screw. After admitting sufficient mercury to fill the tube, which was mounted on an inclined rack, its lower end was closed and the tube removed to a double wall ice bath. Suitable precautions were taken to prevent the water from coming into contact with the ends of the tube.

The excess of mercury was removed by "stroking off" with a plane glass plate in a gimbal mounting. Condensation of moisture was eliminated by a current of dried and cooled air directed at the end of the tube. Six fillings of each tube were made. The average deviation from the mean of the six fillings was approximately four parts per million with a probable error of approximately 1.5 parts per million.

The problem of comparing end standards was reduced to that of comparing line standards by means of platinum contact pieces carrying a line parallel to the plane of contact. These were held against the tube by means of a spring. The line standard thus produced was compared in an ice bath with corresponding known intervals on a nickel steel meter, observations being made for each of four positions of the tube 90° apart. The lengths found were corrected for the added length due to the end pieces which was determined by measuring the distance between the lines on them when the pieces were put in contact.

The values obtained from the tubes in the different positions agreed to within 1μ, the probable error of the set means not exceeding $.35\mu$.

Electrical Measurements.—Measurements were made by the Kelvin double bridge method, the primary standards and five sealed manganin standards being substituted in turn in the same bridge arm. By means of adjustable mercury resistances in the potential leads of the auxiliary one ohm comparison standard to compensate for the corresponding resistances in the leads to the mercury standard and an adjustable shunt

on the auxiliary standard, an exact balance of the bridge could readily be obtained. The auxiliary standard, the ratio coils and their supports were contained in a thermostatically controlled oil bath.

The end bulbs were 4 cm. in diameter, all but one ground joint being eliminated and this was protected by a mercury seal, externally coated with celloidin.

The potential and current connections to the standard were made by sealed-in platinum wires protected from the ice bath by glass tubes, connections with the bridge being made by means of copper conductors and mercury which stood in the terminal tubes at a slightly lower level than the water in the ice bath. Heat condition through the terminals was thereby practically eliminated. The heating due to the test current employed was less than one part per million. In filling the tubes for electrical measurements, an extension to one of the end bulbs was drawn out to a fine point which was broken under mercury after evacuation by means of a ground connection to the Geryk pump at the other end of the tube.

Preliminary Results.—Six fillings of each tube were made. The calculated value of the tube minus its value in terms of the International ohm as agreed to by the International Scientific Committee in 1910 is given in the following table, in which the differnces are expressed in parts per million.

Tube.	Theoretical Minus Observed.	Average Deviation from Mean of Six Fillings.	Probable Error of Mean of Six Fillings.
1	+29	±1.9	±0.65
2	+33	±3.6	±1.22
3	+19	±1.4	±0.48
4	+21	±4.8	±1.50
Mean	+25	±2.9	±0.96

The above differences, expressed in terms of the ohm previously in use at the Bureau of Standards, would be 7 parts per million greater.

The final result is subject to various small corrections still to be determined.

THE DETECTION OF SMALL HEAT EFFECTS AT HIGH TEMPERATURES.[1]

BY WALTER P. WHITE.

IN calorimetric work at ordinary temperatures, stirring is generally necessary to equalize temperatures. Although the need for it is enormously greater in the hot electric furnace, where the surrounding

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

temperature differences are much greater, and convection and radiation are far more active, yet the difficulty of providing for stirring by means of the few materials available at high temperatures is so great that stirring has almost never been tried, and observers have been satisfied to do as well as they could with the uneven temperatures which prevailed in its absence. This has been made easier because the work done has dealt largely with melting points, where quantitative measurement of heat is not required. Although the results are far less perfect that can be obtained at low temperatures, yet they have generally proved sufficient for the purpose in view. Some experimenters, however, have applied the melting point arrangements to the quantitative determination of heat effects, even claiming more than 1 per cent. accuracy. Others, on the contrary, have shown a disposition to reject almost all evidence as to heat quantity based on observations made with the electric furnace. A fair opinion seems to lie between these two views. Determinations in the electric furnace usually show an almost surprising reproducibility, which tends strongly to convey a false impression of accuracy. Large systematic errors, however, are usually present, especially where only one or two thermoelements are used, since the temperature at any given point affords a very imperfect indication of the average value of the temperature in either furnace or charge, while the distribution in both is liable to change both with time and with temperature. It follows, then, that where reproducibility is the main essential results of high accuracy can often be obtained, but for absolute results the very greatest patience and thoroughness are needed in varying the conditions and otherwise eliminating possible systematic errors.

In the detection of slight heat effects, high absolute accuracy is not expected. Hence, in this direction relatively great success can be obtained.

The general principle of the method is simple and fairly familiar. No moving bodies are present, and changes in the temperature of the charge are brought about solely by changing the furnace temperature. The heat effects in the charge are inferred from the changes in its temperature. The temperature of the charge thus depends upon two things, first, the furnace temperature, and second, the heat effects in the charge. The manipulation consists (after the furnace is once loaded) in observing (usually once a minute) the temperature rise, regulating the furnace current accordingly, and observing, either directly or indirectly, the temperature difference of furnace and charge.

The interpretation of the results may, in theory, be made very simple.

The temperature gradient, G, between charge and furnace, serves as the measure of heat flow to the charge. The flow actually is proportional to G, and to the heat-transmittance, F, of the space between furnace

and charge. The exact values of both G and F are usually unknown, and, as already stated, may vary with time, temperature, rate of heating, etc., so that accurate heat determinations by means of them, though possible, are more difficult than has sometimes been realized. But in the *detection* of a small heat effect we have merely to determine the change in G caused by the addition of the effect to the heat which is required to change the temperature of the charge. For instance, a silicate charge (2 grams) of specific heat 0.3, heated 10° per minute, lagged 3° behind the furnace ($G=3°$). Hence 3° in G corresponds to 3 calories per minute. If an inversion absorbing 3 calories and extending over 100° should occur, G would be increased 0.1, or 0.3°, for 10 minutes; if the inversion should take place in one minute G would be doubled, or increased 3°, etc. The detection of small heat effects is easier: (1) The larger G is per calorie per minute, (2) the freer G is from other variations, (3) the quicker the inversion occurs; it is only sluggish inversions whose detection gives any trouble.

G increases with the furnace rate, hence a rapid rate is of the first importance. G also increases with the diameter of the charge, but can be made steadier in the case of a small charge, and the advantage of the small charge appears to be greater on the whole. Fluctuations in the furnace rate cause variations in G; these are partly eliminated by measuring G, not between charge and furnace, but between the charge and another body ("neutral body," or "dead body") closely resembling it. For the best results the other body is used, and the furnace is regulated as carefully as possible, besides. Runs are also made with both bodies alike, to eliminate effects due to the thermoelements or to lack of symmetry between the two bodies, and, of course, repetitions eliminate accidental irregularities. The apparatus now used is small, two platinum crucibles holding 1 c.c. each, 3 mm. apart, and surrounded by a wider porcelain tube to increase uniformity of temperature. A differential thermoelement is also used, which gives directly the temperature difference of the two bodies at any instant. This not only increases accuracy, but saves much tedious computation, necessary when the temperatures are read separately. A complete platinum inclosure shields the whole system from leakage currents out of the furnace coil. In one set of determinations made on different days with the same set-up, conditions were reproduced over a 300° interval with a maximum variation of from 0.03° to 0.06° in the different determinations. This was with a silicate charge and indicates that 1 calorie distributed over 100° could often be detected. But this would be a more difficult case than has yet been found in practice. In one case it was observed that the first heating in each day which, of course, occurred immediately after the furnace had been cold, gave results differing by 0.3° from later heatings, although the furnace was

cooled 300° between all the heatings. This condition reproduced itself at 0.1° on successive days and could, therefore, be largely eliminated, but might prove decidedly deceptive if overlooked, and if the heat effect was, as often happens, one occurring only in the first heating. This circumstance well illustrates the care which must be taken to avoid systematic errors in this kind of work, and the danger of assuming too hastily that the precautions in this direction have been sufficient.

The Capacity and Phase Difference of Paraffined Paper Condensers as Functions of Temperature and Frequency.[1]

By F. W. Grover.

In an ideal condenser the charge is at every instant proportional to the applied difference of potential between its plates, and the capacity is consequently independent of the length of charge or discharge. With alternating current, the current through the condenser is 90° in phase ahead of the impressed electromotive force, and the capacity is independent of the frequency. These conditions presuppose, not only a perfect dielectric, but also a negligible resistance in the leads and plates of the condenser.

Actually, condensers show anomalies which are usually included under the name of absorption effects, and may be summarized as follows: (1) with a steady applied voltage the capacity depends on the length of charge, length of discharge, the interval between charge and discharge, or between discharge and recharge, that is, it depends on the previous history of the condenser. After being discharged, the condenser, if allowed to stand insulated, will yield residual changes. (2) With alternating current the phase difference between the current and the impressed electromotive force falls short of 90° by an angle, usually small, which may be designated briefly as the *phase difference*. Both capacity and phase difference are functions of the frequency.

All these effects vary in magnitude with the temperature, so that the capacity changes to a greater extent with the temperature than can be explained by changes in its dimensions.

A number of theories to account for the phenomena of absorption have been proposed, but most of the existing experimental work has been done with direct current, under conditions which make it difficult to compare the results with theory. The present work was done on condensers having a dielectric of paraffined paper, in which the various effects of absorption are larger and more easily measured than in mica condensers, and to obtain definiteness in the conditions of experiment,

[1] Abstract of a paper presented at the Washington meeting of the Physical Society. April 21 and 22, 1911.

alternating current was used. The capacity and phase difference were measured simultaneously by a method described in detail in a former paper.[1]

In this way curves of the capacity and phase difference of thirteen commercial paraffined paper condensers were obtained for frequencies ranging from 33 to 1,000 cycles per second, and for temperatures ranging between 10° and 35°. From these curves may be drawn the following conclusions for the condensers studied.

1. The changes of capacity with the frequency and temperature are in every case considerably larger than those observed with mica condensers, and are in some cases from ten to fifty per cent. of the value of the observed capacity at the lowest temperatures and highest frequencies. In a general way, the larger the phase difference the greater these changes.

2. The phase differences observed range from about 6′ to the enormous value of 22°. The phase difference of a good mica condenser may be as low as 15 seconds of arc and usually lies under 3′, although mica condensers are often met with which are considerably poorer.

3. The temperature coefficient of the capacity is usually negative with condensers having a small phase difference, and tends to become more and more positive as the phase difference is greater. In the best of the condensers the coefficient is negative and nearly linear, with a tendency to become rapidly numerically larger as the temperature is raised above 30°. In the case of the condensers having large phase differences (1° or more) the temperature coefficient is positive and becomes very rapidly larger as the temperature is increased and the frequency is decreased. With some condensers having a moderate phase difference, the temperature coefficient is negative at the lower temperatures and higher frequencies, and positive at the higher temperatures and lower frequencies.

4. With increasing frequency, the capacity falls, at first rapidly and then more slowly, and finally approaches asymptotically the geometrical capacity (the capacity as unaffected by absorption). In general, these changes become greater as the frequency is increased.

5. In the majority of cases the phase difference increases with rising temperature, the changes being particularly great with condensers having large phase differences.

6. The phase difference decreases with increasing frequency except in those cases where the I^2r loss in the connections and plates is considerable, when the phase difference may actually increase with the frequency. This effect is particularly noticeable in telephone condensers made by rolling up together sheets of tin foil and paper. In one of the condensers studied, the I^2r loss in the plates and connections was about three times as large at 1,000 cycles as the loss in the dielectric.

[1] Bull. Bureau of Standards 3, p. 371, 1907.

7. The use of paper condensers as reference standards in work with *direct current* is not allowable, and should be permitted in *alternating current* work, only after a study of the behavior of the condenser under different conditions of temperature and frequency has shown that the performance of the condenser meets the requirements laid down by the work in question.

In the theoretical part of the paper the fundamental equations of the theories of Maxwell,[1] Houllevigue,[2] Pellat[3] and Hopkinson[4] are developed, and the observed curves are discussed in the light of these theories. It is shown that of these theories none are in accordance with the facts, but that if, as suggested by von Schweidler,[5] the Pellat equations be extended so as to read as a summation of terms, only a limited number of constants are necessary to represent the observations. Constants have been calculated for a number of the condensers, from which the geometrical capacity may be calculated, and it is shown that the physical interpretation of these equations, as given by von Schweidler, can be made to explain some apparent anomalies of the observed curves.

The Measurement of Inductances with very small Time Constant.[6]

By F. W. Grover and H. L. Curtis.

MEASUREMENTS of inductances with small time constants are becoming increasingly important. For example, such diverse cases may be cited as the measurement of the small residual inductances of so-called "non-inductive" resistance coils, the inductances of multipliers for voltmeters or other measuring instruments, and the determination of the small inductances used in wireless telegraph circuits.

The method of measurement in any given case depends on the value of the resistance which is associated with the inductance. Thus a method adopted to the measurement of a coil of a few microhenrys, or smaller, and having a resistance of the order of one hundredth of an ohm is not suitable for the determination of the inductance of a coil of the order of 10,000 ohms.

Measurements of coils of as low inductance as one microhenry have

[1] Elect. and Mag., I., §§ 328–330.

[2] Jour. de Phys., 6, pp. 113, 120, 1897.

[3] Ann. Chem. et Phys., 18, p. 150, 1899.

[4] Phil. Trans., 166, p. 490, 1876.

[5] Ann. der Phys., 24, p. 711, 1907.

[6] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

been made, among others, by Wien and Prerauer,[1] Giebe[2] and Orlich,[3] all of whom were able to detect differences of inductance as small as a few centimeters.

In the method here employed, the inductance to be determined is compared by direct substitution with a standard, whose inductance can be calculated from its dimensions, in an alternating current bridge, using a frequency of 1,500 cycles. The difference in inductance between the coil to be measured and the standard was measured by the change of capacity necessary to reëstablish balance in the Anderson's bridge, when the unknown was inserted in place of the standard.

The standards used were resistances consisting of two manganin wires stretched parallel to one another at a measured distance apart. In order that no error should be introduced by the small difference in resistance between the standard and the test coil, changes of resistance in steps of one tenth ohm were obtained by substituting for manganin links, resting in mercury cups, copper links of the same diameter, form and size. For continuous resistance changes of less than 0.1 ohm, a variable resistance of a form suggested by Dr. F. Wenner and Mr. J. H. Dellinger was employed. Two straight glass tubes of different diameters, mounted vertically and united at the bottom by a cross tube, are filled with mercury. Two copper wires of diameters closely approximating those of the cross sections of the tubes may be raised or lowered in the mercury, giving a continuous variation of resistance, free from any unsteadiness, as great as 0.00001 ohm. With this form of instrument the change of resistance is accompanied by a change of inductance almost negligibly small. In the present instance, the maximum change of inductance for a change of resistance of 0.1 ohm, as determined by the use of the manganin and copper links, was only about 10 cm.

The above described method of measurement was applied with success to the determination of the inductances of coils of resistances as high as 1,000 ohms. Parallel wire standards were in every case prepared of the same nominal resistance as the coil to be measured. For the larger values the difference in inductance between the coil and the standard was measured by the change in the setting of a calibrated variable inductance on substituting one for the other. For coils of 1,000 ohms, where a small capacity in parallel with the coil has an appreciable effect on the phase of the current, the balance may be obtained by varying a capacity shunted around one of the coils, as was done by Brown[4] and Giebe.[5]

[1] Wied. Ann., 53, pp. 772, 928, 1894.
[2] Ann. der Phys., 24, p. 941, 1907.
[3] Zs. f. Instrk., 29, p. 241, 1909.
[4] PHYS. REV., 29, p. 369, 1909.
[5] Verh. Deutsch. Phys. Gesell., 12, p. 949, 1910.

In coils of 100 ohms or more, the effect of the capacity between the different turns of the winding is usually greater than the inductance, so that the current through the coil leads the impressed electromotive force. We may then regard the effective inductance of the coil as negative and equivalent to a residual capacity c assumed to be joined between the terminals of the coil, and of such a value that $-l = cR^2$, where l is the effective inductance, and R is the resistance of the coil.

For resistances larger than 1,000 ohms, where it becomes difficult or impracticable to prepare standards, whose constants may be calculated, the inductance may be determined by placing the coil as a shunt on a standard of known effective inductance and of about 1,000 ohms resistance. The change of balance of the bridge on joining the coil to be tested may be measured either by means of a variable inductance in the main circuit, or by the change in a variable capacity, also shunted around the standard. In still a third method the coil to be measured is placed in one of the arms of a bridge of which the ratio arms are of very unequal resistance, the effective inductance of the remaining three arms being known.

In the measurements of one-ohm coils a change of inductance of one centimeter was appreciable, and the measurements made with parallel wire standards were consistent with those in which the circular form of reference standard was used to about this order of accuracy. Equally small time-constants of ten-ohm and one hundred-ohm coils could be measured with about the same precision as in the case of the one-ohm coils. With 1,000 and 10,000 coils the difficulties increase. Capacity effects must be very carefully guarded against. Metal surfaces associated with the coils as in the ordinary forms of resistance box are a source of indefiniteness in the constants of the coils. It is also noticeable that the capacity between the windings of coils of such high resistance is not constant, but changes with the time, when the measuring current is flowing, the capacity becoming greater. This suggests that the shellac acts as a dielectric with appreciable absorption, the temperature coefficient of the capacity being large and positive.

It is to be noticed that the apparent capacity effect of a coil of high resistance, when used in an alternating current bridge, is largely dependent on the absolute potential of the coil. To measure the true capacity of the coil, the potentials should be so adjusted that the middle point of the resistance of the coil is at zero potential. In the case of several high resistance coils in series, in a bridge, this condition cannot be realized for all the coils, and in general the measured capacity of the sum will not be the same as that calculated from the measured values for the separate coils.

RESISTANCE COILS FOR ALTERNATING CURRENT WORK.[1]

BY H. L. CURTIS AND F. W. GROVER.

THE measurement of alternating currents frequently requires the use of resistance coils having small reactances. A plain bifilar winding has usually been relied upon in the case of coils whose resistance lay between 1 and 1,000 ohms. Of such coils, those below 50 ohms have a positive reactance, while those above 100 ohms have a negative reactance. The authors have made experiments in the design of coils to make these effects as small as possible. The aim has been to reduce the time constant to not more than 3 or 4×10^{-8}, and at the same time to keep the dimensions of the coil such that when immersed in oil an expenditure of one watt will not raise its temperature more than one degree.

Coils of four different values have been experimented upon, viz., 1, 10, 100 and 1,000 ohms. A 1-ohm coil which meets the above requirements may be made from a strip of manganin having a width of 3 mm. and a thickness of 0.1 mm. This is folded upon itself, the two parts being separated by a thin sheet of mica or silk. A 10-ohm coil may be made either of strip manganin in the same manner as above, using a width of 1 mm. and a thickness of 0.1 mm. or of three 30-ohm coils in parallel, the 30-ohm coils being made of the same wire as is used in the 100-ohm coil to be described. The 100-ohm coil may be made of double silk insulated manganin wire, having a diameter of 0.24 mm. It is wound in a single layer bifilar winding, using a spool having a diameter of 2.5 cm. Using wire of this diameter, wound as indicated, the inductance and capacity effects are very nearly balanced. The 1,000-ohm coil is made of wire having a diameter of 0.1 mm. and is wound in five sections each of 200 ohms. Each of these sections is a single layer bifilar winding. It is important that a coil made of several sections in series shall be wound upon an insulating spool. For this purpose a porcelain spool is quite satisfactory. The coils are to be shellaced and baked in the usual manner.

In making coils it is not found that every coil of the same resistance, made according to the same specifications, has the same effective inductance when completed. However, the variation should not be large. The following table gives the worst values which were found when the above specifications were used.

Resistance in Ohms.	Inductance in Microhenrys.
1	+ 0.04
10	+ 0.3
100	− 1.6
1000	−16.

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

Recent Determinations of the Elementary Electrical Charge.[1]

By Wm. W. Coblentz.

THE value of the elementary quantity of electricity, or the free charge of a single ion or electron, derived by Planck[2] from his radiation theory is $e = 4.69 \times 10^{-10}$ E.S. He calls attention to the fact that the formula is derived with absolute exactness, and that the numerical value of this constant will depend upon the accuracy of the experimental determination of the constants of radiation.

This numerical value of e is based upon Kurlbaum's value of the Stefan constant σ of total radiation, $\sigma = 7.061 \times 10^{-15}$ erg/cm^2 deg^4, and upon Lummer and Pringsheim's value of the Wien constant, b, of spectral energy distribution, $b = 0.2940$ cm. deg.

Some preliminary experiments on the diffuse reflection of platinum black shows that Kurlbaum's value of σ requires a correction (increase in value) of 6 to 7 parts in 1,000. Applying this correction to Planck's value of e gives $e = 4.72 \times 10^{-10}$ E.S.

A year ago the writer presented to this society some preliminary data on the value of the constant, b, based on 14 spectral energy curves, from which the mean value was $b = .2945$ cm. deg., with the possibility of the final value being a trifle higher, say, $b = .2950$. This gives a value of $e = 4.7 \times 10^{-10}$ E.S.

The most recent and the most consistent value of e obtained by Millikan is $e = 4.89 \times 10^{-10}$ E.S., which is considerably higher than usual. To obtain such a value from Planck's radiation theory would require a value of $b = .2978$ (an increase of 1.3 per cent. over $b = .2940$) or an increase in σ of 3.6 per cent.; and $c_2 = 14{,}800$. These latter values of b and c_2 are all very much higher than seem possible from the present experiments on the black body. On the other hand from a recent inquiry into the instruments to be used in measuring radiation in absolute value (various observers differ by as much as 10 per cent.) preliminary to a redetermination of the value of σ it appears that the most reliable values of σ may be higher than the one now commonly accepted.

The high value of $b = .2945$ to $.2950$, and of $c_2 = 14{,}600$ to $14{,}800$ and the agreement of these values with those required by extrapolation of the optical temperature scale; also the close agreement ($\Delta e = 3$ per cent.) of the values of the elementary charge, e, obtained from electrical and radiation methods, seen to indicate the approach to a place where we can harmonize the various conflicting data and can feel that there is some basis for the underlying theories.

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] Vorlesungen ü. Wärmestrahlung, 1906.

A METHOD FOR ELIMINATING THE EFFECT OF ALL CONNECTING RESISTANCES IN THE THOMSON BRIDGE.[1]

BY F. WENNER.

THE arrangement of conductors for a Thomson bridge is shown in Fig. 1. Here the low resistances under comparison are designated by X and N, the resistances for the main ratio by A and B, and of the auxiliary ratio by α and β. Farther, the connecting resistances from the points where the current and potential terminals divide to the terminals of the ratio sets are designated by x_1, x_2, n_1 and n_2. These letters are used both to designate the conductors and to represent the values of their resistances, C represents the value of the resistance between X and N from branch point to branch point while L designates the low resistance in parallel with the auxiliary ratio. If then the conductors are all *linear* and the bridge is balanced we have the following relation between the resistances:[2]

$$X = N\frac{A+x_1}{B+n_1} + \frac{A+x_1}{B+n_1}C\frac{\alpha+x_2}{\beta+n_2+\alpha+x_2} - C\frac{\beta+n_2}{\beta+n_2+\alpha+x_2}. \quad (1)$$

This equation may be put in a more convenient form if we substitute

$$\frac{A}{B}(1+a) \text{ for } \frac{A+x_1}{B+n_1}, \quad \frac{A}{B}(1+b) \text{ for } \frac{\alpha+x_2}{\beta+n_2},$$

and

$$D \text{ for } \frac{C}{N}\frac{\alpha+x_2}{\alpha+x_2+\beta+n_2}$$

which give

$$X = N\frac{A}{B}[1+a+D(a-b)]. \quad (2)$$

If by suitable adjustments a and b can be made so small as to have no appreciable effect this reduces to the equation for a simple bridge. In order to make these adjustments possible, low resistances, forming a part of x_1, x_2, n_1 and n_2, are connected between the potential terminals and the ends of the ratio sets. These resistances can be varied continuously, or in small steps, at least on one side of each ratio.

Starting with the ratio A/B and X/N approximately equal

1. With q and q' as branch points, the bridge is balanced by an adjustment of x_1 or n_1.

[1] Abstract of a paper presented at the Washington meeting of the Physical Society April 21 and 22, 1911.

[2] Wm. Thompson, Phil. Mag., 24, p. 149, 1862.

2. With p and p' as branch points and the connection L between X and N open[1] the bridge is balanced by an adjustment of x_2 or n_2.

3. With p and p' as branch points and the connection L between X and N restored, the bridge is balanced by an adjustment of N or a proportional adjustment of the main and auxiliary ratios.

Where the connecting resistances are small in comparison with the ratio sets and starting with the three ratios X/N, A/B and α/β approxi-

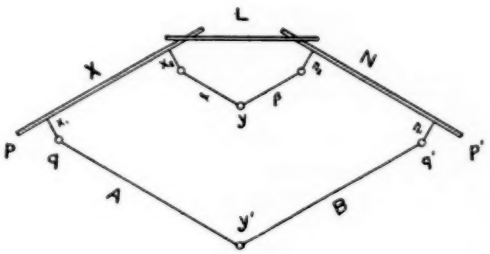

FIG. 1.

FIG. 2.

mately equal; the first operation makes a negligibly small, the second makes b equal to a, and the third fulfills the conditions of the fundamental equation. The three adjustments then give

$$X = \frac{A}{B} N, \tag{3}$$

which is the equation for the corresponding simple bridge.[2]

As the three adjustments are not entirely independent, any change in making the second or third disturbs the first slightly, it may be necessary in some cases to repeat them in the same order using those already made as first approximations. Where the measurements are made in this way the accuracy is as high or higher than where any of the connecting resistances are determined and the corrections applied, while the time and attention necessary for making the measurements and calculations are considerably less.

[1] J. H. Reeves, Proc. Phys. Soc. London, 14, p. 166, 1896.

[2] W. Jaeger and H. Diesselhorst, Wiss. Abh. d. P. T. R., 4, p. 120, 1906.

The conditions that must be fulfilled on order that a four terminal resistance may have a definite value are pointed out, Farther it is shown that there can be but three definite values and one of these is the sum of the other two. If one of the three values is zero the effect is the same as if the conductors were in the form of a wire and we shall call it *linear* to distinguish it from the other case which we shall call *non-linear*.

In using the Thomson bridge with non-linear conductors the current through the potential connections to or from the ratio sets causes a change from the normal current distribution in such a way as to destroy the relations given by the fundamental equation. A more extended theory is given showing that, under certain conditions easily realized, correct values are obtained whether the resistances are linear or non-linear and that, if the adjustments here outlined are carried out, equation (3) gives the relation between the resistances with which we are concerned even in those cases in which equations (1) and (2) are not valid.

As the success of the method depends upon having suitable variable low resistances, the form used which was developed jointly by J. H. Dellinger and the author, is shown in section in Fig. 2. Here the letters have the following significance; *a* a hard rubber tube, *b* mercury, *c* and *c'* copper terminals amalgamated where they come in contact with the mercury, *d* an amalgamated copper rod, *e* a spring clamp for holding the copper rod in position. Electrical connection is made through the terminal blocks *c* and *c'* and the resistance is varied by changing the position of the copper rod.

Where alternating current is used the conditions which a four terminal conductor must fulfill in order that it have a definite inductance as well as resistance are pointed out. Farther, it is shown that where the measurements are carried out as outlined above, adjusting inductances as well as resistances, the same simple relations are obtained, both between the inductances, and the resistances. Unless the inductances as well as the resistances are adjusted a balance can not be obtained except with non-inductive conductors.

If a direct current galvanometer is used and commutated synchronously with the current or the galvanometer is of the type having the field excited by a current from the same source as the test current it is possible by adjusting resistances only to get a zero deflection but this does not necessarily signify that the bridge is balanced.

An Enclosed Arc for Spectroscopic Work.[1]

By James Barnes.

During the past few years the author has been engaged in the study of the spectra of a number of substances in the arc burning in gases under reduced pressure. A number of vessels were made for holding the arc, but none gave perfect satisfaction until the one, which is briefly[2] described here, was built. It consists of a large bell-jar ground to fit an iron disc. Between the rim of the jar and the disc a small amount of vaseline or better, stopcock[3] lubricant is placed. The external air pressure upon the jar when the inside air is removed makes this joint almost air-tight, the small leakage is quickly removed by a Geryk pump. With a mercury seal around this joint it is possible to exhaust with a Gaede pump to very low pressures. The arc is made by moving the lower pole by means of an external electro-magnet. The positive pole and the bell-jar are cooled by water coils. The jar has a short side tube closed by a quartz plate which allows the radiations a free exit.

The arc under reduced pressure gives spectra which are not only purer than those obtained from the arc in air at atmospheric pressure but the lines are narrower and sharper, which is of much importance in the measurements of wave-lengths. The narrowness of the lines is best shown by the interference bands they produce when passed through an interferometer. A Fabry and Perot instrument was adjusted with about 5 mm. separation of plates and the interference rings focused on the slit of a Hilger constant-deviation spectroscope. It was found that the lines of the iron, copper and brass arcs *in vacuo* produce bright interference rings much more distinct than those one obtains with the same arcs in air, using the same voltage and current. In the case of substances like cadmium it is almost impossible at atmospheric pressure to get any interference fringes at all in any of the lines, but when one of the iron poles is bored out and filled with the metal and then used in the arc *in vacuo* the fringes come out very clearly, in fact almost as sharp as those obtained with the Hereus cadmium lamp. This arc has been run for three quarters of an hour with one filling and probably can be used much longer with proper adjustment of the current. Such an arc will be of use in interference methods such as is used for the determination of indices of refraction where a large number of narrow bright lines throughout the spectrum are required.

Observations were made on the drop of potential between the poles

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] For details see an article soon to be published in the Astrophysical Journal.

[3] See Travers' Study of Gases, p. 24.

of the arc in air at a pressure of 1 cm. as the strength of the current was changed and the results plotted and compared with those of the arc in air at atmospheric pressure. They show that with small current, 3 amperes or less, the drop is about the same for both cases, but from this point up to the higher currents used, about 16 amperes, the curves gradually separate till in the case of copper the difference is about 10 volts, for carbon 20 volts.

	Potential Drops Across Poles. Current, 16 Amperes.		
	Cu	C	
In vacuo	23	40	The voltage of the line was 220.
In air	32	60	

At times the arc will leave one pole and end on a metal part of the vessel, often having a length of over 10 cm. with a current-strength between 2 and 3 amperes and potential fall about 130 volts. This discharge is very interesting, striations have been observed in it, particularly with carbon poles.

BRYN MAWR, PA.,
April, 1911.

THE SPECTRA OF ALUMINIUM, COPPER AND MAGNESIUM IN THE ARC UNDER REDUCED PRESSURE.[1]

BY JAMES BARNES.

THIS paper contains the results of some observations upon the spectra of aluminium, copper and magnesium in the arc where the pressure of the air was reduced to about 1 cm. The enclosed arc was described in the above paper and the rest of the apparatus used has for the most part been described in former[2] papers.

In aluminium there is an unmistakable difference in the relative intensities of many of the lines in the arc *in vacuo* compared with their intensities in the arc in air, all other conditions being kept constant. The lines showing the greatest charge are λλ4663, 3587, 2631 and 2816. The so-called oxide bands are just as intense as they are in air. A beautiful fluting with four heads makes its appearance in this arc. It was first found by Basquin in a rotating arc in hydrogen. The wave-lengths of these bands have been measured as accurately as possible using iron lines as standards from the new international system.

Copper has without doubt a larger number of lines affected by the reduction of pressure than any of the elements so far tried. Mention should be made of λλ4675, 4587, 4378, 4177 for they are just visible on

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] Astrophysical Journal, 27, 152, 1908, and 30, 14, 1909.

the plates of longest exposure while they are among the strongest in the arc in air.

Besides the charges in the relative intensities of some of the magnesium lines recorded in a former[1] paper the following lines λλ2790, 2798, 2929 and 2937 are all affected in the same way. The so-called oxide and hydride bands appear clearly on the spectrum plates of the arc *in vacuo*.

The results of these observations may be divided into two classes:

1. The bands which have been attributed to compounds of oxygen and hydrogen with aluminium, magnesium and calcium all appear in the arc in air under reduced pressure. Whether or not they are true oxide or hydride bands one must admit is still an open question, for it can always be claimed that there is enough oxygen left in the vessel surrounding the arc or sufficient hydrogen occluded in the metal to produce these bands. It might be of interest to state in this connection that the hydrogen lines could not be found on the plates while the nitrogen bands showed very clearly.

2. With regard to the lines, the effect of the reduction of the pressure is in general to increase the intensity of the spark lines of aluminium and magnesium and to diminish many of the arc lines of copper. Whatever the explanation of this may be one can state that the arc *in vacuo* is a step between the arc in air and the spark. The lines which are affected do not belong to the principal or subordinate series in Kayser and Runge's arrangement.

BRYN MAWR, PA.,
April, 1911.

THE THEORY OF DISPERSION AND THE RESIDUAL RAYS.[2]

BY O. W. RICHARDSON.

THIS paper discusses the reflection, at normal incidence, from the surface of an insulating medium, of light whose period is close to that of one of the principal periods of vibration of the medium.

It is shown that the well-known difference between the position of the energy maximum in the residual rays and the corresponding natural frequency is about what would be expected from the values of the constants entering into the usual dispersion formulæ. This is particularly true of fluorite which shows the greatest difference.

The case of two natural periods close together is considered and the results are compared with Nichols's experiments on the reflection of

[1] Astrophysical Journal, 21, 74, 1905.

[2] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

infra-red rays from quartz. The agreement between the experimental results and the theory is satisfactory.

PALMER PHYSICAL LABORATORY,
PRINCETON UNIVERSITY,
April, 8 1911.

POSITIVE THERMIONS FROM SALTS OF ALKALI EARTHS.[1]

BY C. J. DAVISSON.

THE experiments constitute an extension of investigations begun by O. W. Richardson on the nature of positive thermions from salts in general. The nature of the thermions is inferred from determinations of their specific charge. These determinations depend on measurements of the magnetic deflections of the ions moving in a vacuum in a uniform magnetic field. The values obtained for salts of the alkaline earths have in all cases been found capable of classification under two heads:

1. Those corresponding to one half the specific charge of the metal ion of the salt in electrolysis.

2. Those due to some common impurity, probably potassium. The inference is reached that the positive thermions from salts of the alkaline earths are single atoms of the metal of the salt minus a single electron.

PALMER PHYSICAL LABORATORY,
PRINCETON UNIVERSITY,
April 3, 1911.

THE RÔLE PLAYED BY GASES IN THE EMISSION OF POSITIVE THERMIONS FROM SALTS.[2]

BY C. J. DAVISSON.

EXPERIMENTS have been carried out to determine if any appreciable part of the thermionic currents from surfaces of heated salts is carried by the gas in contact with these surfaces. Determinations of the specific charge of the thermions by means of their electro-magnetic deflections have been made at various low gas pressures in various gases. The results indicate that even when the gas pressure is sufficient to cause a marked increase in the thermionic current at given constant temperature no appreciable part of the current is carried by ions of the gas.

PALMER PHYSICAL LABORATORY,
PRINCETON UNIVERSITY,
April 3, 1911.

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

The Difference in the Photoelectric Effect Caused by Incident and Emergent Light.[1]

By Otto Stuhlmann, Jr.

TRANSPARENT metal films, made by sputtering in vacuo from a cathode were investigated for their photoelectric properties. A beam of ultra-violet light at normal incidence, showed that the photoelectric effect was greater in the emergent than in the incident side. The metals investigated, when films were used that were so thin that their absorption can be neglected, gave the following results for the ratio of emergent to incident effect.

Magnesium	1.03
Copper	1.08
Zinc	1.11
Silver	1.07
Tin	1.15
Platinum	1.17
Lead	1.12

Selenium and carbon gave unsatisfactory results.

Palmer Physical Laboratory,
Princeton University,
March, 1911.

Spectroscopic Evidences of Molecular Clustering.[2]

By W. W. Strong.

1. *Solvates.*—Compounds of solvent (such as water or methyl alcohol) and dissolved salt (such as uranous chloride) are shown by the characteristic solvate bands of the salt. In a mixture of the solvents, the salt will show the two absorption spectra superimposed. For a given temperature, there is a definite percentage of each solvent required in order that each set of solvent bands should have the same intensity. This proportion of a given solvent may be defined as a measure of the persistency of the given solvent bands. The persistency of each band in a solvent spectrum seems to be the same. On account of the definiteness of some solvent spectra, it may be considered that the absorbing centers are definite compounds and that the "atmosphere" of solvent consists of a single kind of molecules and that the number of these is so considerable that atoms or molecules outside this "atmosphere" have no influence on the frequencies of the vibrations within.

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

This work is being carried out with financial aid generously furnished Prof. Harry C. Jones by the Carnegie Institution of Washington.

The persistency of solvent bands for different salts varies. The alcohol and water bands of neodymium chloride (0.5 normal) are of the same intensity when there is 8 per cent. water and 92 per cent. methyl alcohol present. For samarium chloride a smaller proportion of water is required while in the case of uranous chloride and uranous bromide 40 per cent. water and about 60 per cent. alcohol is required, the uranous salts being about 0.2 normal. The presence of free acid or of other salts usually decreases the persistency of the water bands compared with the alcohol bands. In the above example of neodymium chloride as the concentration is decreased, the alcohol bands increase in persistency.

The effect of rise in temperature is to increase the relative persistency of the absolute bands (with reference to the water bands). A very marked instance of this can easily be shown with a pocket spectroscope in the case of uranous chloride dissolved in water and methyl alcohol. If the proportion of solvents is such as to show the water and alcohol bands of equal intensity at room temperature, then at 70° or 80° C. the water bands will be found to disappear almost completely.

Isomeric alcohols may show characteristic bands. For instance, the corresponding bands of neodymium chloride in isobutyl alcohol are of considerably greater wave-length than the bands in butyl alcohol and the bands for propyl alcohol are of greater wave-length than in isopropyl alcohol.

2. *Aggregates.*—The presence of free acids and salts has been shown to change the wave-lengths of uranyl, uranous and some neodymium bands. This change of wave-length is apparently a continuous one. In some cases as aqueous solutions of uranyl intrate and uranyl sulphate or neodymium chloride and acetate, the absorption of the two salts are quite different. In most cases when one of these salts is transformed to the other salt, the change from the one spectrum to the other is a continuous one. Thus the uranyl nitrate bands of a nitric acid solution can be gradually changed to the acid uranyl chloride bands by adding hydrochloric acid.

Uranyl Bands.

	a	*b*	*c*	*d*	*f*	*g*	*h*
Nitrate in nitric acid.	4790	4670	4510	4370	4125	4000	3900
Chloride in hydrochloric acid.	4950	4800	4635	4450	4280	4050	4015

If it is assumed that a characteristic absorption spectrum is due to a more or less stable compound, then the above changes indicate the existence of series of compounds and these will be called aggregates. There will be nitric acid uranyl aggregates, neutral nitrate uranyl aggregates, etc. In some cases the aggregates may have their own characteristic bands. For instance an acid solution of neodymium chloride in ethyl alcohol has strong and characteristic bands at λλ3695 and 3760.

Mixture of varying amounts of two salts in the same solvent seems to result in some cases in the formation of aggregates consisting of both salts, the frequencies of the resulting bands depending on the relative amounts of the two salts present.

Acid aggregates of uranous salts may be much more stable than neutral aggregates. For instance, uranous nitrate is very unstable but uranous chloride dissolved in nitric acid (the absorption spectra is very different from that of uranous chloride) will remain unoxidized for hours. Neutral uranous salts in water heated to 80° or 90° C. form a black precipitate, but if some free acid is present, the uranous salts are much more stable.

Aggregates form solvates that possess absorption bands that are as characteristic as those formed by the pure neutral salt.

The addition of hydrogen peroxide to a uranous salt solution oxidizes the salt to the uranyl conditions. Spectrophotographs of these oxidization reactions show the complete independence of the uranyl and uranous spectra.

In the reduction of the uranyl salts by the hydrogen process it was found that very concentrated solutions of uranous salts were obtained from ether solutions of the uranyl salts. The reduction of the uranyl salts does not seem to be due to the presence of nascent hydrogen for the addition of a small amount of nitric acid and zinc to an aqueous solution of uranyl chloride does not result in any uranous salt being formed although the amount of nitric acid added is not great enough to change the uranyl chloride bands to the uranyl nitrate bands.

Selective Action on Solvates.—The addition of hydrogen peroxide was found to oxidize the hydrate and alcoholate (both being present in approximately equal amounts in the solution) at the same rate. On the other hand, when potassium or calcium nitrate is added to such a solution the water bands become very weak or even disappear while the alcohol bands do not become weaker at all. Sometimes selective precipitation may take place and only the alcohol bands remain in the absorption spectrum. The addition of sodium chlorate to a very concentrated solution of uranous bromide in water and alcohol produces selective precipitation. In general the addition of an oxidizing agent shows a selective action on the uranous bands due to different solvates.

The Effect of Dilution.—As the uranyl sulphate and nitrate bands in aqueous solutions have different wave-lengths, it might be expected that for great dilutions, the uranyl bands would have the same wave-lengths for both salts. Changes of concentration from 1.5 to 0.003 normal of the uranyl nitrate and sulphate showed very little change of wave-length. This very small change consisted of a shift of the nitrate bands to the red and the sulphate bands to the violet. Similar experi-

ments should be carried out on the bands of uranyl chloride and nitrate in acetone as these have quite different wave-length.

The above results may be explained by assuming that the uranyl aggregates break up but little as the concentration is decreased and that these aggregates may act as ions. Since the intensity of the uranyl bands does not decrease greatly with dilution one may consider that this intensity depends upon the constitution of the aggregate.

THE ELASTIC PROPERTIES OF A SERIES OF IRON-CARBON ALLOYS.[1]

BY C. W. WAGGONER.

THIS work is a continuation of a study[2] the writer is making on some of the physical properties of a special series of iron-carbon alloys in which the constituents, other than the carbon, are practically constant. This study was made to determine, if possible, any definite connection between the carbon content of these alloys and their elastic properties. The actual tests were carried out under the supervision of Professor C. R. Jones, by two senior students, Messrs. Crewson and Patterson, on a 20,000-pound Riehle standard testing machine in the testing laboratory of West Virginia University. Test samples were given the same heat treatment as was used in the magnetic tests,[3] namely annealing for two hours at 1000° C. to remove any hardening effect due to machining or to the previous rolling in the manufacture.

The results may be briefly summarized as follows:

1. The elastic properties, like the magnetic properties, show a critical point between .9 per cent. and 1 per cent. carbon. This is to be expected from the phase diagram for iron.

2. The maximum strength increased with the carbon content up to the critical percentage of carbon and then decreased. The maximum strength for pure iron being about 40,000 pounds per square inch.

3. The breaking strength follows the same law as the maximum strength, the slope of the curve plotted with breaking strengths as ordinates and carbon percentages as abscissas being greater throughout the lower ranges of carbon.

4. The methods of locating the elastic limit are such as to call in question any results; but there is some evidence in favor of a slight increase in the elastic limit up to the critical percentage of carbon and then a decrease as the carbon content is decreased.

5. The results on the modulus of elasticity need further study, but

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] PHYS. REV., Vol. XXVIII., p. 393, June, 1909.

[3] *Loc. cit.*

present results indicate a slight decrease with increase in carbon throughout the range of carbon studied.

6. The total elongation varies almost exactly in an inverse proportion to the carbon content. Here, too, there is a slight change in the curve at the critical carbon percentage.

7. The reduction of area decreases with the increase of carbon content; a small change in carbon making relatively a large change in the reduction of area up to the critical percentage of carbon, but beyond this critical percentage the decrease in reduction of area is not so marked as for the lower range of carbon content.

WEST VIRGINIA UNIVERSITY.

THE DEFLECTION POTENTIOMETER CONSIDERED AS A GENERALIZED NULL INSTRUMENT.[1]

BY H. B. BROOKS.

Outline.—The potentiometer has until a few years ago been regarded only as a null instrument. The deflection potentiometer for voltage measurements, described by the writer about five years ago, showed the possibility of making precision voltage measurements with a potentiometer in which an appreciable part of the result is given by the reading of the galvanometer. More recently the question of measuring current in the same manner has been investigated. This brought up new problems, which have been solved, and the theory has been extended so that all measurements within the range of a given potentiometer may be made under the condition of current in the galvanometer circuit. The limitation, "galvanometer current equal to zero," is thus removed, and the potentiometer method is therefore generalized. The chief advantages secured by this combination of null and deflection methods are rapidity of working, and the ability to work with unsteady currents and voltages if necessary.

THE SATURATION VALUE OF THE SPECIFIC INTENSITY OF MAGNETIZATION OF COBALT AT VARIOUS TEMPERATURES.[2]

BY W. W. STIFLER.

THE saturation values of the specific intensity of magnetization of cobalt were determined at intervals of 100° to 150° from 22° C. up to 1000° C., and from that temperature up to 1150° C. at much

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] Abstract of a paper presented at the Washington meeting of the Physical Society April 21 and 22, 1911.

smaller intervals. The method used was that described by Weiss[1] and consisted in observing the deflections produced when a small ellipsoid was jerked out of a helix placed in a strong longitudinal field. For the higher temperatures this helix was surrounded with heating coils. The sample was protected from oxidation by placing it in an exhausted tube of glass or quartz. The temperatures were measured by a thermojunction which was sealed into the tube and which was separated from the cobalt by a thin strip of mica.

External fields up to 6,900 gausses were used, giving fields in the ellipsoid up to 5,000 gausses. Below 350° C. this was not sufficient to produce saturation. Hence the saturation value was determined by plotting σ against $1/H$ and $1/H^2$, where σ is the intensity of magnetization per gram, and extrapolating. The extrapolated values are probably accurate to 1 per cent. Above 350° C. saturation was reached with the fields used.

The value of σ at room temperature is 160. It decreases gradually to 113 at 800° C. after which it falls off very rapidly with increase of temperature, the cobalt ceasing to be ferro-magnetic at about 1080° C. The curves plotted with σ and temperature as coördinates are identical for two samples tested and are of the form required by the electron theory of magnetism. The results are discussed from the point of view of this theory.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS.

THE RADIANT EFFICIENCY OF ARC LAMPS.[2]

BY H. P. GAGE.

THE object of the present investigation is to determine the radiant efficiency of arc lamps and the mechanical equivalent of light. The definition here used of radiant efficiency is:

$$\frac{\text{Energy of the visible part of the spectrum}}{\text{Total energy radiated}} = \frac{L}{R}.$$

Using the symbols, R = total energy radiated,

W = energy passing through 8 cm. layer of water,
L = energy visible part of spectrum.

The ratio L/R or W/R was obtained by a slight modification of the method of Ångström. After dispersing the spectrum of a light source

[1] Journ. de Phys., 9, pp. 373–393, May, 1910.

[2] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

the infra-red was removed by an opaque screen. The light was then reassembled by a mirror to a white spot. The energy of this white light was compared by means of a radiomicrometer with white light of equal intensity and like color from the same source which had not been robbed of its infra-red. In some cases owing to the small value of L compared with R, L was compared with the intermediate quantity W.

In a previous paper (October 15) the reasons were indicated for choosing the value of L as the energy of the spectrum included between the limits $.4\mu$ and $.68\mu$. These are briefly: The small photometric effect of all energy of greater wave-length than $.68\mu$, and the greater certainty of setting the cut off screen at this than at greater wave-lengths.

The most important results follow.

Source.	Eff. L/R Per Cent.	Light Equivalent of Energy. Candles per Watt.
Positive crater, right angle carbon arc.	8 to 12 depending on current.	30
Right angle lamp alternating current.	6.5 to 8.5	21
Yellow flame arc.	15.4	39
Yellow flame, arc stream.	39.	
Brilliant white.	14.6	21
Hefner, recalculated from Angström for limit $.68\mu$.	.363	21.3
Nernst lamp viewed through $CuSO_4$ solution.	100	39.5

The greatest efficiency of 39 per cent. was found in the case of the arc stream between yellow flame electrodes, the tips being shaded. The light equivalent of energy was found to be as high as 30 candles per watt with white light and almost 40 candles per watt with light distributed more in the visually intense part of the spectrum.

A Heterochromatic Photometer.[1]

By H. P. Gage.

A PHOTOMETER constructed on the same principle as the Lummer-Brodhun photometer except that in place of the usual cubical prism there was substituted a piece of ordinary looking glass, part of the silver being scratched off with a sharp knife. It was found that if instead of removing large areas of the silver, small scratches were made, these scratches could be made to disappear with differently colored lights

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

when with large areas, a sharp match never could be made. With this apparatus it was possible to make fairly sharp settings with such differently colored lights as acetylene, the right angle arc, daylight, the yellow flame arc and the Hefner lamp. When it comes to comparing red light with green light, however, the results are not at all satisfactory unless very low intensities are used.

Fig. 1.

The form of pattern adopted was as shown in the figure, the black representing the silver removed.

ULTRA-VIOLET FROM THE ARC.[1]

BY H. P. GAGE.

IN experimenting with different substances in the arc it was found that uranium gave a very nearly continuous spectrum from the visible to the ultra-violet as far as .22μ. The following electrodes will give a spectrum with rather weak lines on a continuous background. Make a tube of thin sheet iron or "tin" 1/4 inch inside diameter, fill with powdered uranium oxide (U_3O_8). Use as lower electrode, connect to the positive terminal and pass 6 amperes. The negative terminal may be carbon. If the current is reversed a rich line spectrum will be obtained.

The amount of ultra-violet light in a source may be photometered by using a Lummer-Brodhun photometer with a screen towards the unknown source which will transmit only the wave-lengths desired. The ultra-violet light is made apparent to the eye by using a screen coated with anthracene instead of white paper. Examples of measuring the photographic brilliancy of several arc lamps.

HEAT OF EVAPORATION OF WATER AT 100° C.[1]

BY ARTHUR WHITMORE SMITH.

IT is well known that the vapor rising from boiling water carries with it a certain amount of water in a finely divided state, but nevertheless still liquid. Even with a steam separator 1 per cent. or more of the total mass may be water, and unless precautions are taken the percentage of moisture in the stream from an ordinary boiler is greater than this.

These considerations lead to a feeling of very great uncertainty when one studies the methods which have been used for the determination of the heat of evaporation of water. If the steam used contained 1 per

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

cent. moisture, the familiar number 537 is 1 per cent. too low. As far as I know no attempt has ever been made to determine the heat of evaporation from a quiet surface of water at 100° C. where there is small chance of spray being thrown into the vapor above.

This paper describes a new form of calorimeter in which the water is evaporated by a gentle current of air passing over its unruffled surface. Heat is supplied by an electric current, both E and I being measured in terms of a Weston cell. The temperature is maintained constant by regulating the air current to allow the evaporation to proceed just fast enough to use the heat as it is delivered by the current.

Each result is computed from two experiments, in one of which about 36 grams of water are evaporated and in the other only about 9 grams. The corresponding amounts of heat are supplied by the electric current plus small corrections. The *difference* between the two heats eliminates these corrections, and when divided by the *difference* between the corresponding amounts of water gives 541.3 ± 0.2 calories per gram for the heat of evaporation of water at 100° C.

Check experiments made and computed in the same way and with the same apparatus, but allowing the water to boil, give the old value of about 538 calories per gram.

UNIVERSITY OF MICHIGAN.

A TUBULAR ELECTRODYNAMOMETER FOR VERY HEAVY CURRENTS.[1]

BY P. G. AGNEW.

TO obtain the same current distribution for both alternating and direct current, it is usual to strand the windings of the field coils of electrodynamometers. For very heavy currents, this becomes a matter of extreme difficulty. An entirely different method of obtaining the same end is employed in the present instrument. The field at an outside point due to a straight cylindrical or tubular conductor is independent of any skin effect if we have axial symmetry. The field "coil" consists merely of two concentric heavy copper tubes, thus giving a circular field between the tubes. There are two moving coils astatically placed between the tubes, one on either side of the inner tube, and suspended by a phosphor bronze strip. The common axis of the tubes is placed in a horizontal position in order to allow the vertical suspension. While the distribution is not the same an alternating as on direct current, the magnetic field in the space between the tubes and hence the torque is the same. For cooling it is arranged so that water may be passed through the inner tube. The instrument was designed to carry 5,000 amperes,

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

and it will carry 1,000 amperes continuously without water cooling. Magnetic impurities on the moving system are exceedingly troublesome, the requirements being even more exacting than in the moving coil galvanometer.

THE SILICON DETECTOR USED WITH SHORT ELECTRIC WAVES, AND THE THEORY OF CONTACT RECTIFIERS.[1]

BY ERNEST MERRITT.

THE writer has used the silicon detector with waves ranging from 15 cm. to 50 cm. in demonstrating the properties of Hertz waves to a class, and finds it highly satisfactory. The detector is amply sensitive even when used without any E.M.F. and with a d'Arsonal galvanometer of only moderate sensibility. To damp out the low frequency oscillations that would otherwise be produced in the induction coil and connecting wires, the oscillator—of the Righi type—was connected to the coil through two Geissler tubes. Under these circumstances, and with a Wehnelt interrupter, the indications were remarkably steady and free from disturbances.

In connection with the explanation of the rectifying action of detectors of this type, attention is called to the probable influence of the sudden change in specific conductivity which occurs at the contact. If the metals used are of different conductivity, or if the contact is imperfect, there will be a layer of transition in which the specific conductivity changes rapidly. The equation of continuity requires that in this transition layer, as in all conductors, div. $i = 0$, where i is the current density. If the electric field is E and the conductivity C, we therefore have

$$\text{div. } i = \text{div. } CE = 0 = C \text{ div. } E + E \text{ grad. } C.$$

In homogeneous isotropic conductors the conductivity is constant at all points and grad. $C = 0$. In such cases therefore div. $E = 4\pi\rho = 0$ and there is no free charge on the interior. But in the transition layer C is not constant and grad. C, and in consequence ρ, may differ very appreciably from zero. The transition layer will therefore contain an excess of positive ions for one direction of current and an excess of negative ions when the current is reversed. If the negative ions only are free to move, and if the material is of such a nature that its molecules do not readily liberate electrons to make up for a deficiency, the conductivity of the transition layer will thus depend upon the direction of the current.

It can readily be shown that the change in conductivity with the direction and magnitude of the current will be such as to lead to a relation

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21, 1911.

between current and E.M.F. of the same general form as that determined experimentally. For small currents it can also be shown that the rectified current through such a contact should be proportional to the square of the applied alternating E.M.F. This conclusion is in agreement with the experimental results of Austin.

Photo-electric Potentials of Thin Cathode Films.[1]

By Paul H. Dike.

IT has been found by Professor Millikan that aluminum, copper, silver and some other metals when exposed for considerable lengths of time to the action of ultra-violet radiation in very high vacua, gradually increase in photo-electric activity, giving values for the photo-electric potential which are unprecedentedly high, running up to 25 volts for copper. Von Baeyer and Gehrts, taking precautions to avoid the reflection of the electrons projected from the plate by the action of the light, obtained a maximum of 6.3 volts for aluminum, gold and copper. Values not exceding three volts have been found by other observers.

In the work here described an attempt was made to repeat Millikan's high values for the potential by preparing and testing the metal surface in the same vacuum without exposure to the air, so as to prevent as far as possible the formation of surface films. The first method tried was to use the plate to be tested as cathode during a long discharge, giving a fresh, clean surface. The potential obtainable could be increased to four volts at most with copper and iron, the metals tested, an increase over the usual values but not a great one. Another method of preparing the metallic surface is to form a cathode deposit of the metal on a plane surface, and test it without exposure to the air. As a result of three trials agreeing among themselves in their general features it may be said that a platinum cathode film on glass is photo-electrically active even when of the utmost tenuity—down to 10^{-8} cm. in thickness. The potential rises to a somewhat uncertain maximum of from 12 to 18 volts at a thickness of about 5×10^{-8} cm. and at 10^{-7} cm., drops suddenly to a minimum of about one volt, and from that value it increases very gradually with thickness of film to 1.5 or 2.0 volts. These values are approximate, and probably would have been much higher if electronic reflection had been avoided as was done in a later type of tube. In this the cathode could be turned out of the way while the film was being exposed to the light and the walls of the tube were much farther from the plate under test, while diffused light was also nearly eliminated. In this tube very thin films did not give as high potentials depositing on

[1] Abstract of a paper presented before the Washington meeting of the Physical Society. April 21–22, 1911.

quartz, but slightly thicker layers gave persistently high potentials, and an aging effect appeared. A freshly deposited film renders the plate inactive for several minutes but a gradual change takes place and the potential obtainable on exposure to ultra-violet light increases for several hours going up finally to 25 or 30 volts. A platinum plate cleaned with French chalk gave a potential of 6.2 volts when first placed in the tube. On being covered with a cathode deposit of platinum not more than 10^{-7} cm. in thickness and standing for several hours it gave a potential of 44 volts. A slight increase in the thickness of the film restored the original lower potential and the high values could not be regained till the film had been removed by using the plate as cathode and then covering it with a fresh deposit.

Very thin films of platinum cathodically deposited have been shown to possess extreme photo-electric activity as measured by the velocity with which the electrons are projected, giving potentials as high as 44 volts, which is about twenty times the potential ordinarily obtained and nearly double Millikan's highest reported value for copper.

A slight increase beyond the critical thickness restores the metal to its normal condition.

The same effect is obtained even when platinum is deposited on platinum.

Further experiments with thin films are in progress.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF WISCONSIN,
April 17, 1911.

A NEW DETERMINATION OF THE SELECTIVE RADIATION FROM TANTALUM.[1]

BY EDW. P. HYDE.

IT has been shown elsewhere[2] that, if two incandescent bodies are at a color match and have different luminous efficiencies, then one of the bodies radiates selectively with respect to the other. The existence of a color match is a consequence of there being approximately the same energy distribution in the visible spectra. A difference in the luminous efficiencies indicates that, for the entire spectrum taken as a whole, there exists a difference in the distribution of the radiated energies from the two sources. If two bodies are not selective in their radiation with respect to one another,

[1] Abstract of a paper presented at the Washington meeting of the Physical Society, April 21 and 22, 1911.

[2] Edw. P. Hyde, Jour. of Frank. Inst., 169, 439; 170, 26; 1910.

it was shown that at a color match they must have the same luminous efficiency. The test for a difference in their radiating selectivities is then logically that which has been stated above. A color match may be determined with considerable accuracy with the aid of a photometer. The luminous efficiencies, in case the substances are mounted as incandescent lamp filaments, may be determined by standard methods. In the paper already noted there were presented results on various types of incandescent lamps when compared with a black body. Among other things it was found that untreated carbon was very closely non-selective. These results did not include corrections due to losses in efficiency resulting from the cooling effects of the supports for the filaments, to energy dissipated in the base and the leading-in and connecting wires, and to the absorption of the radiated luminous energy by the glass bulb and the deposits thereon. In some recent work[1] these losses have been investigated. It seemed worth while to redetermine the relative selectivity of tantalum and carbon taking into account the losses just mentioned. Two special lamps, one with an untreated carbon filament, the other with a tantalum filament, were used in which these losses could be carefully measured. The results are included in the following table:

Approx. Black Body Temp.	Measured Luminous Efficiencies in Lumens per Watt.		Corrected Luminous Efficiencies in Lumens per Watt.		Ratio of the Luminous Efficiency of Tantalum to that of Carbon.	
	Carbon.	Tantalum.	Carbon.	Tantalum.	Present Results.	Previous Results.
1420° C.	$.37_3$	$.48_1$	$.41_9$	$.51_9$	1.2_4	1.3
1610	1.4_1	1.7_0	1.5_9	1.8_2	1.1_4	1.15
1780	3.1_5	3.5_6	3.5_2	3.7_6	1.0_7	1.1

It is to be noted that the corrections for the losses mentioned above have changed but little the previous values for the ratio of the luminous efficiency of tantalum to that of untreated carbon, obtained by using ordinary lamps.

A Kinetic Theory of Gravitation.[2]

By Charles F. Brush.

THE author discusses at length the origin of the energy acquired by a falling body, and concludes that the gathered energy comes from the ether through which the body falls. Conversely, equivalent

[1] Hyde, Cady & Worthing, Elec. World, March 9, 1911, p. 624. The complete paper will appear shortly in the Trans. of the Ill. Eng. Soc., and in the London Illuminating Engineer.

[2] Abstract of a paper presented at the Minneapolis meeting of the Physical Society, December 30, 1910.

energy is restored to the ether when the body is raised against gravitative attraction.

The ether is assumed to be endowed with vast intrinsic kinetic energy in wave form. The waves are of such low frequency, or otherwise of such character, that they pass through all bodies without obstruction other than that concerned in gravitation. They are propagated in straight lines in every conceivable direction, so that the wave energy is isotropic, being in this respect like radiation in the interior space of a furnace with uniformly heated walls. Distribution of the ether's intrinsic energy is uniform throughout the universe except as modified by the presence of matter. Any kind of ether waves capable of exerting motive action on the atoms or molecules of matter will fulfil the requirements.

Atoms are imagined to be continually buffeted in all directions by the ether waves in paths almost infinitesimally short, but without collision because neighboring atoms follow *very* nearly parallel paths. The moving atoms are likened to particles of a precipitate suspended in turbulent water.

Each atom or molecule is regarded as a center of activity due to its kinetic energy of translation derived initially from the ether. There is continual absorption and restitution of the ether's energy, normally equal in amount. But the ether is permanently robbed of as much of its energy as is represented by the mean kinetic energy of the atom. This energy deficiency in the ether is not wholly local, but extends indefinitely into space, diminishing as the square of the distance increases.

A body of matter is pictured as casting, in effect, a spherical energy-shadow consisting of the sum of the shadows of its constituent units, the depth or intensity of the shadow varying with the inverse square of the distance from the body's center of mass. Another body, at any distance, will cast a similar shadow, and the two shadows will intersect, each body being partially shielded by the other from waves coming from that direction; the extent of the shielding effect depending directly on the mass of the shielding body.

Of the several components into which the composite motion of each atom can be resolved, that one lying in the direction of an attracting body will be greatest, because the waves from that direction, being partially intercepted by the attracting body, are weakest; and the atom will be *pushed* in that direction by the superior waves behind it. If free to fall, the atom will continually absorb more energy from the stronger waves behind it than it restores to the weaker waves in front, and will thus acquire additional kinetic energy of translation in the line of fall, measured directly by the number of waves involved, *i. e.*, by the distance

moved. Conversely, if the atom be forced away from the attracting body, restitution of energy will exceed absorption, and the energy expended in moving the atom against attraction will be transferred to the ether.

It will be seen that gravitation is a *push* toward the attracting body, and not a pull. It is clear also, that the velocity which a falling body can acquire tends asymptotically to a limit, which is the velocity of the ether waves which push it—the velocity of light, if transverse waves are involved.

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ERRATA.

Page 64. Preparation and Properties of the Heusler Alloys. The photographs in the right hand column of Fig. 4 from top to bottom are 24, 36, 37, 54; in the left hand column from top to bottom are 44, 41, 38.

Page 324. A New Method of Producing Ripples. After publishing this note Dr. Hugo Schultze called my attention to the fact that he had already described the methods of ripple formation therein discussed. (See *Zeitschrift für Instrumentenkunde*, p. 150, 1906, and p. 151, 1907; also *Tätigkeitsberichten der Phys. Techn. Reichsanstalt*, 1905 and 1906.) I wish to take this opportunity of acknowledging priority to him and to express the regret that the former articles escaped my notice.

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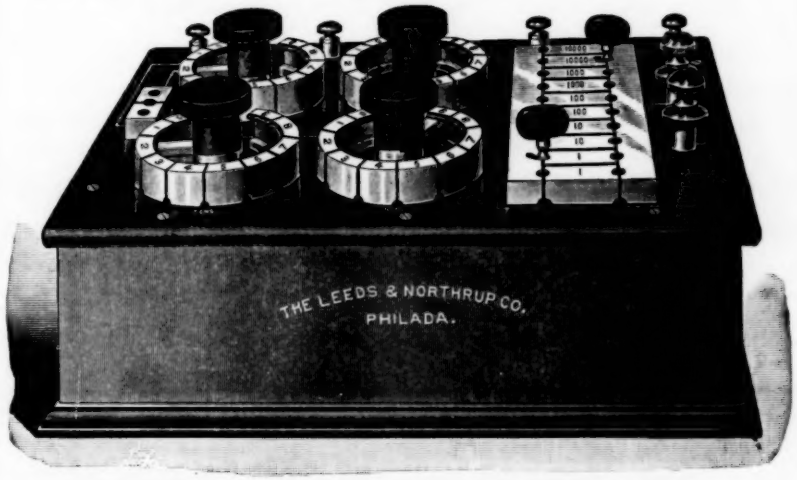

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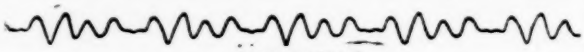

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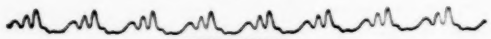

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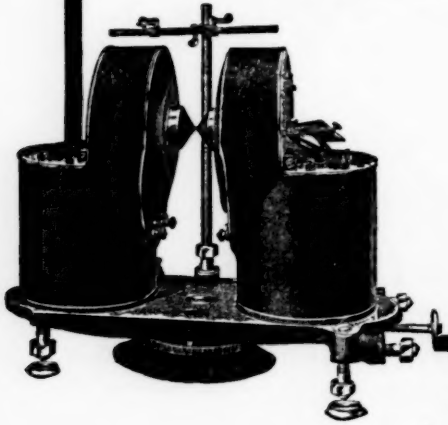

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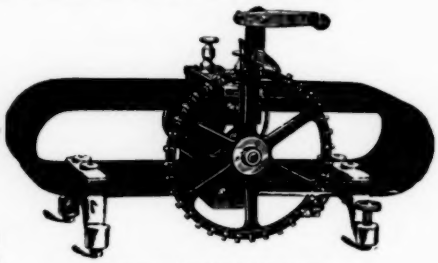

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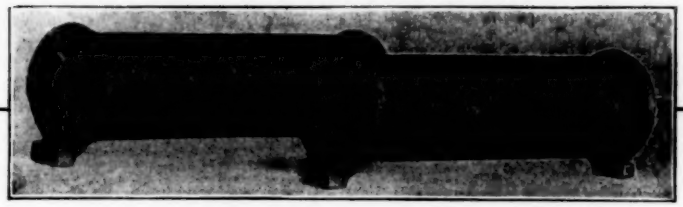

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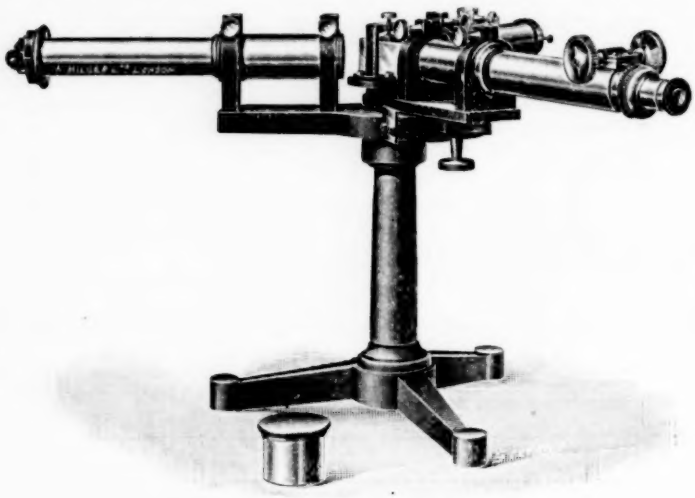

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